

Kinder Morgan Linnton Terminal – LNAPL Mobility Analysis

PREPARED FOR: Oregon Department of Environmental Quality
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DATE: August 2015

1.0 Introduction

The purpose of this Technical Memorandum is to evaluate the LNAPL mobility in the vicinity of the barrier wall and extraction system and the behavior of the LNAPL based on water level and system operational fluctuations at the Kinder Morgan Liquids Terminals (KMLT) Linnton Terminal (the Site), located at 11400 NW Saint Helens Road in Portland, Oregon (Figure E-1). The analysis includes evaluation of LNAPL thicknesses, elevations, and baildown testing results conducted in 2014 and 2015 in the vicinity of the barrier wall.

The barrier wall and extraction system includes a 216-foot-long, 30-foot deep, impermeable barrier wall and associated hydraulic gradient control system (CH2M HILL, 2011a) intended to prevent LNAPL migration to the river within the interim action target area identified in the interim action feasibility study (CH2M HILL, 2011b) and shown in Figure E-1. The extraction wells in operation in the barrier wall vicinity include (EW-1, EW-2, EW-3, EW-5, EW-6, EW-7 and MW-19). A network of piezometers (PZ-1 through PZ-9) were installed between 2012 and 2014 to aid in monitoring conditions in the vicinity of the barrier wall. Details on the barrier wall system are included in CH2M HILL (2011a, 2013a, 2013b, 2014a, and 2014b). Construction completion diagrams for the barrier wall, extraction wells and piezometers are included in Appendix F of the Groundwater Source Control Evaluation (SCE).

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2.0 Site Overview

The Conceptual Site Model is discussed in detail in Section 2.5 of the Groundwater Source Control Evaluation (SCE), with cross-sections of the hydrogeology in the vicinity of the barrier wall presented in Figures 2-2, 2-3 and 2-9 of the Groundwater SCE. A summary of previous LNAPL studies on-site is presented in Section 3.1.2 of the Groundwater SCE. As shown in Figure E-1, the extent of LNAPL in the barrier wall vicinity extends parallel to the Willamette River from MW-3 to MW-20 and upgradient of the river from the barrier wall and piezometers (PZ-1 to PZ-9) to MW-27 and MW-28. As described in the 2010 LNAPL mobility study at the site (CH2M HILL, 2011b), LNAPL in the vicinity of the barrier wall was not found to be present above residual saturations.

3.0 Evaluation of LNAPL Mobility

To facilitate an evaluation of LNAPL elevations and transmissivity in the vicinity of the barrier wall, monthly product recovery in the barrier wall vicinity was temporarily discontinued starting in April 2014. To update the current understanding of LNAPL behavior and mobility in the vicinity of the barrier wall, the following data was evaluated:

- LNAPL thicknesses and elevations (2012 to 2014)
- LNAPL recovery data from the barrier extraction system (2012 to 2014)
- LNAPL baildown testing results (2014 and 2015)

3.1 LNAPL Elevations

A pattern of increased LNAPL thicknesses in the vicinity of the barrier wall during times of low water levels has been observed since monitoring of the barrier wall piezometers began in 2012. Several diagnostic gauge plots of groundwater elevation vs. LNAPL elevation were developed for the north end, middle and south ends of the barrier wall (Figures E-2a, E-2b, and E-2c). The increased LNAPL thickness in the wells is directly related to occurrence of seasonally low aquifer water levels between 10 and 13 feet NAVD 88. This elevation corresponds to the zone where LNAPL was observed during previous investigations along the bank (CH2M HILL, 2011b). During low-water conditions, the lower water levels in the piezometers allow residual LNAPL in this area to drain from the pore spaces and accumulate within the piezometers. The mobility of this LNAPL was evaluated by measuring LNAPL transmissivity and is discussed in the following sections.

3.2 LNAPL Transmissivity

To evaluate LNAPL mobility trends over time, water and LNAPL recovery data from the barrier extraction system was used to calculate an approximation over time of the average LNAPL transmissivity near barrier wall. The LNAPL transmissivity (T_n) is estimated via the following equation (ASTM, 2012):

$$T_n = \frac{Q_n T_w}{Q_w} \left(\rho_r + \frac{S_{skim}}{S_w} \right) \text{Where:}$$

Q_n = NAPL extraction rate in gallons per day

Q_w = water extraction rate in gallons per day

T_w = transmissivity of water in feet squared per day = K^*b , where

K = hydraulic conductivity in feet per day and

b = saturated thickness of the aquifer in feet

ρ_r = LNAPL-to-water density ratio

S_{skim} = Skimming drawdown in feet of NAPL

S_w = Water drawdown in feet of NAPL

The parameter values used in this analysis are summarized in Table E-1. The oil-water extraction ratio (Q_n/Q_w) is based on the total water and LNAPL extraction rates from all barrier extraction wells. For the purposes of this analysis, an average hydraulic conductivity (K) and saturated thickness (b) was applied based on results from the Step Testing conducted in the vicinity of the barrier wall in 2014 (see Appendix C of the Groundwater SCE).

The results of the site-wide NAPL transmissivity calculations are shown in Figure E-3, and show a clear trend of decreasing NAPL transmissivity in the barrier wall vicinity over time. Varying the K and b seasonally would result in a lower transmissivity of water during low-water conditions and a higher transmissivity of water during high-water conditions, though the decreasing trend over time would be preserved, with NAPL transmissivity values of less than 0.1 cubic feet per day since 2013.

The LNAPL transmissivity of individual wells was also calculated from LNAPL baildown and recovery data at select wells in the barrier wall vicinity (EW-1 and PZ-7 on the north end of the wall, PZ-3 in the middle of the wall, PZ-5 and PZ-8 on the south end of the wall). These analyses are presented in Attachments E-1 to E-4 and the results are summarized in Table E-2 which range from less than 0.03 to 0.2 ft²/day which correlate well with the oil water ration LNAPL transmissivity analysis, confirming the LNAPL mobility is below recovery endpoints as defined by the Interstate Technology & Regulatory Council (ITRC, 2009).

4.0 Summary and Conclusions

The decreasing NAPL transmissivity trend over time (Figure E-3), coupled with the LNAPL elevation plots (Figures E-2a, E-2b, and E-2c) indicates that temporary increases in LNAPL thickness in the vicinity of the barrier wall are related to low water levels and not an increase in mobility. This analysis supports the following conclusions:

- LNAPL mobility remains low in the vicinity of the barrier wall
- LNAPL thicknesses fluctuate seasonally in response to changes in groundwater levels

5.0 References

- ASTM, 2012. E2856 – Standard Guide for Estimation of LNAPL Transmissivity. January.
- CH2M HILL, 2011a. *Interim Action Basis of Design – Barrier Wall System*, Kinder Morgan Linnton Terminal. July 14.
- CH2M HILL. 2011b. *Interim Action Feasibility Study*, Kinder Morgan Linnton Terminal. March 17.
- CH2M HILL. 2013a. *Interim Action Barrier Wall System-Construction Completion Report*, Kinder Morgan Linnton Terminal. December 13.
- CH2M HILL, 2013b. *Extraction Well and Piezometer Installation Report*, Kinder Morgan Linnton Terminal. July 22.
- CH2M HILL, 2014a. *Extraction Well Installation and Redevelopment Installation Work Plan*, Kinder Morgan Linnton Terminal. August 19.
- CH2M HILL, 2014b. *Extraction Well Installation and Redevelopment Installation Report*, Kinder Morgan Linnton Terminal. November 24.
- Interstate Technology and Regulatory Council (ITRC). 2009. Evaluating LNAPL Remedial Technologies for Achieving Project Goals. December. <http://www.itrcweb.org>. Accessed March 2015.

TABLE E-1

Parameters for Calculation of LNAPL Transmissivity in Vicinity of Barrier Wall*Kinder Morgan Liquids Terminals, Linnton Terminal*

Parameter	Value	Source Reference
NAPL extraction rate (combined from all extraction wells)	Combined rate from all extraction wells	Data from Oil-water separator
NAPL extraction rate (combined from all extraction wells)	Combined rate from all extraction wells	Calculated from totalizer readings
Hydraulic Conductivity (K in ft/dy)	22	Average hydraulic conductivity [1]
Saturated Thickness (b in ft)	15	Average saturated thickness from Step Test Memo [1]
LNAPL-to-water density ratio (ρ_r)	0.85	[2]
S_{skim}	0.2	[2]
S_w	2	[2]

References:

- [1] Step Drawdown Testing Results are presented in Appendix C of the *Groundwater and Bank Soil Source Control Evaluation Report, Kinder Morgan Linnton Terminal*
- [2] ASTM, 2012. *E2856 – Standard Guide for Estimation of LNAPL Transmissivity*. January.

TABLE E-2

LNAPL Transmissivity Estimates in Vicinity of Barrier Wall*Kinder Morgan Liquids Terminal, Linnton Terminal*

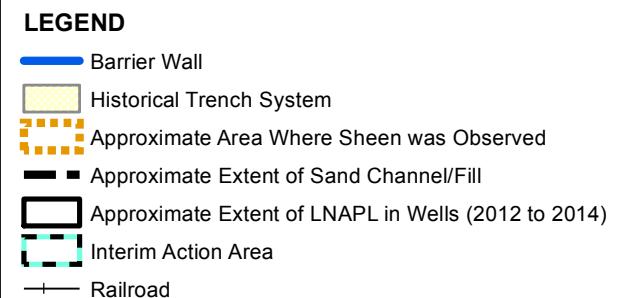
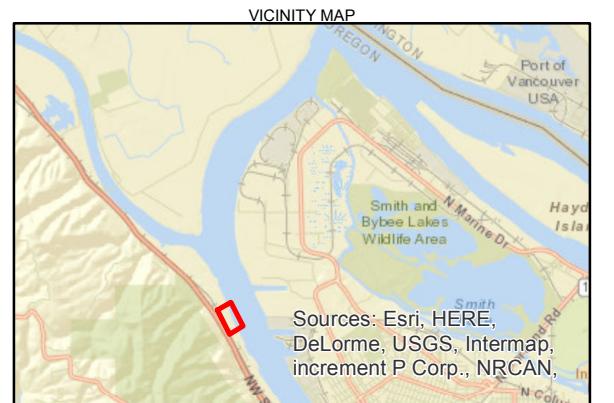
Well ID	<i>LNAPL Transmissivity (in ft²/dy)</i>			
	Generalized Bouwer and Rice (1976)	Cooper and Jacob (1946)	Cooper, Bredehoeft and Papadopoulos (1967)	Thiem Equation
EW-1	NA	0.1	0.09	0.08
EW-6	0.04	0.2	0.09	NA
PZ-3	0.001	0.03	0.003	NA
PZ-8	NA	0.002	0.09	NA

NOTES:

NA - Method not applied

Transmissivity estimates calculated using the API LNAPL Transmissivity Workbook (API, 2012):

API Regulatory and Scientific Affairs Department, 2012. *A User Guide for the API LNAPL Transmissivity Workbook: A Tool for Baildown Test Analysis*, API Publication 46xx, September 2012.



Linniton Terminal Wells

- Hydraulic Control Well
- Shallow Monitoring Well/Extraction Well
- Monitoring Well - Shallow
- Monitoring Well - Deep
- Piezometer
- 3-Foot Diameter Cistern



FIGURE E-1
Site Layout and Interim Action Area
Kinder Morgan Liquids Terminals, LLC
Linniton Terminal
11400 NW St. Helens Road
Portland, Oregon

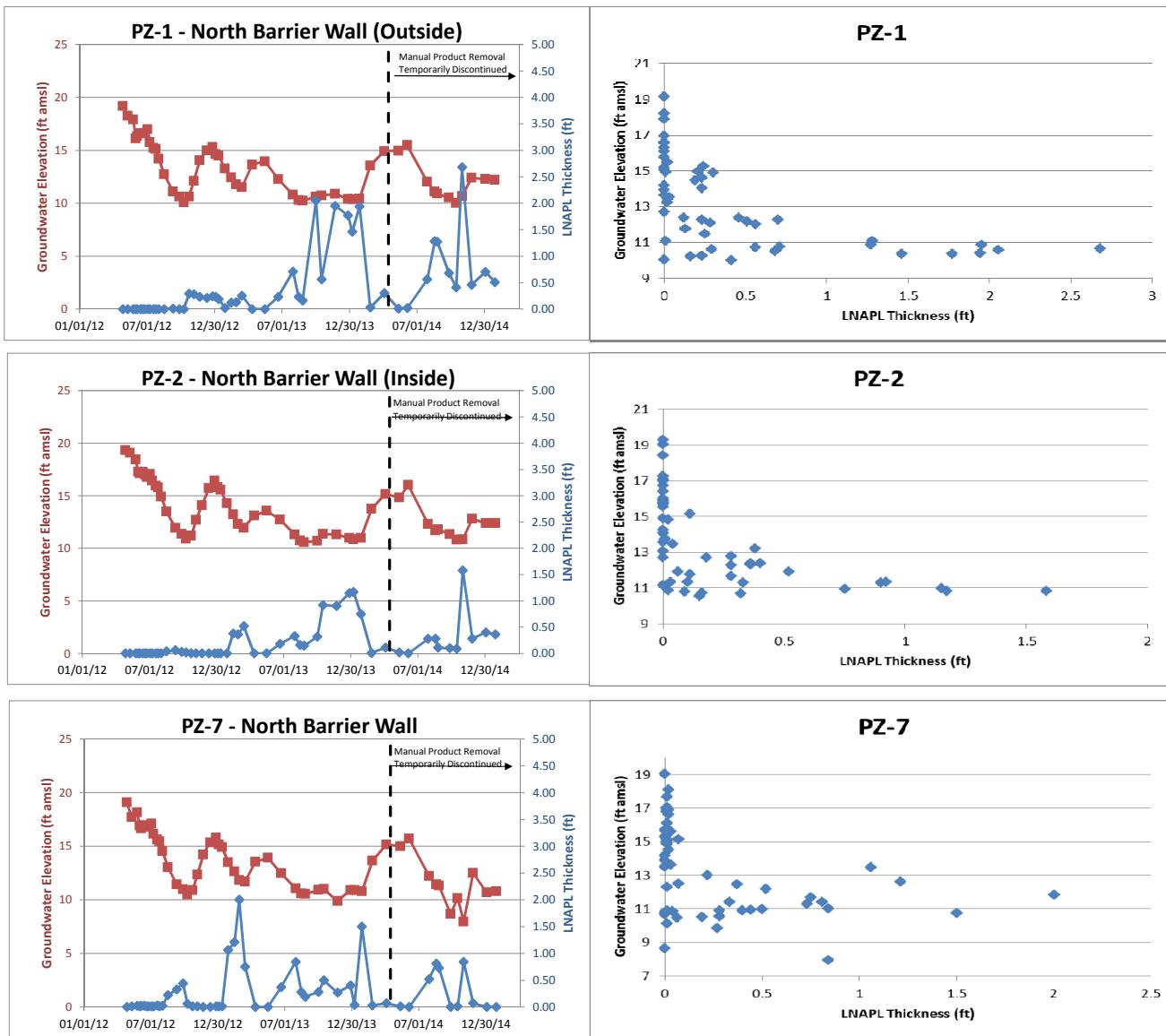


FIGURE E-2a
Groundwater and LNAPL Elevations - North End Barrier Wall
Kinder Morgan Liquids Terminals, Linnton Terminal

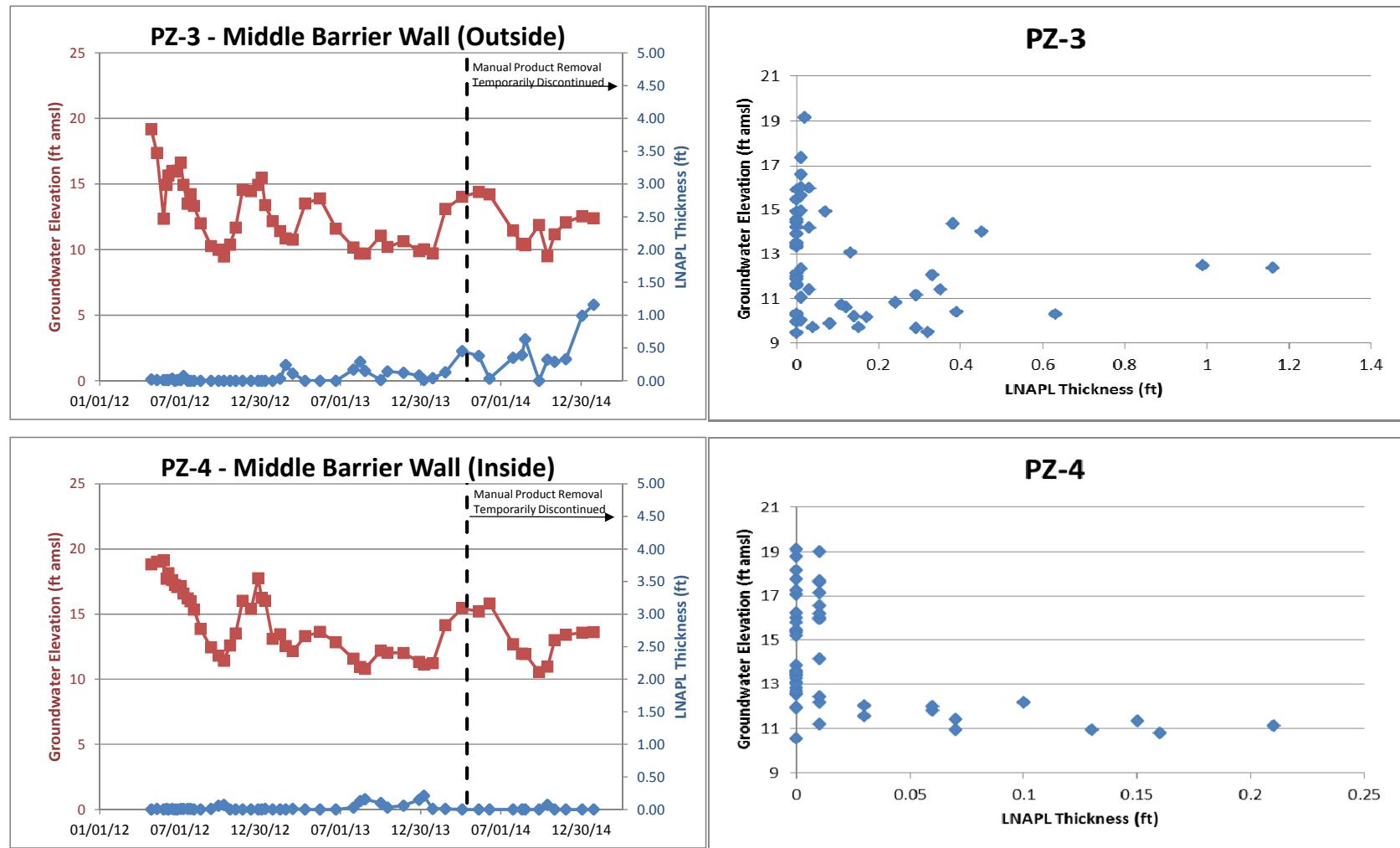


FIGURE E-2b
Groundwater and LNAPL Elevations - Middle of Barrier Wall
Kinder Morgan Liquids Terminals, Linnton Terminal

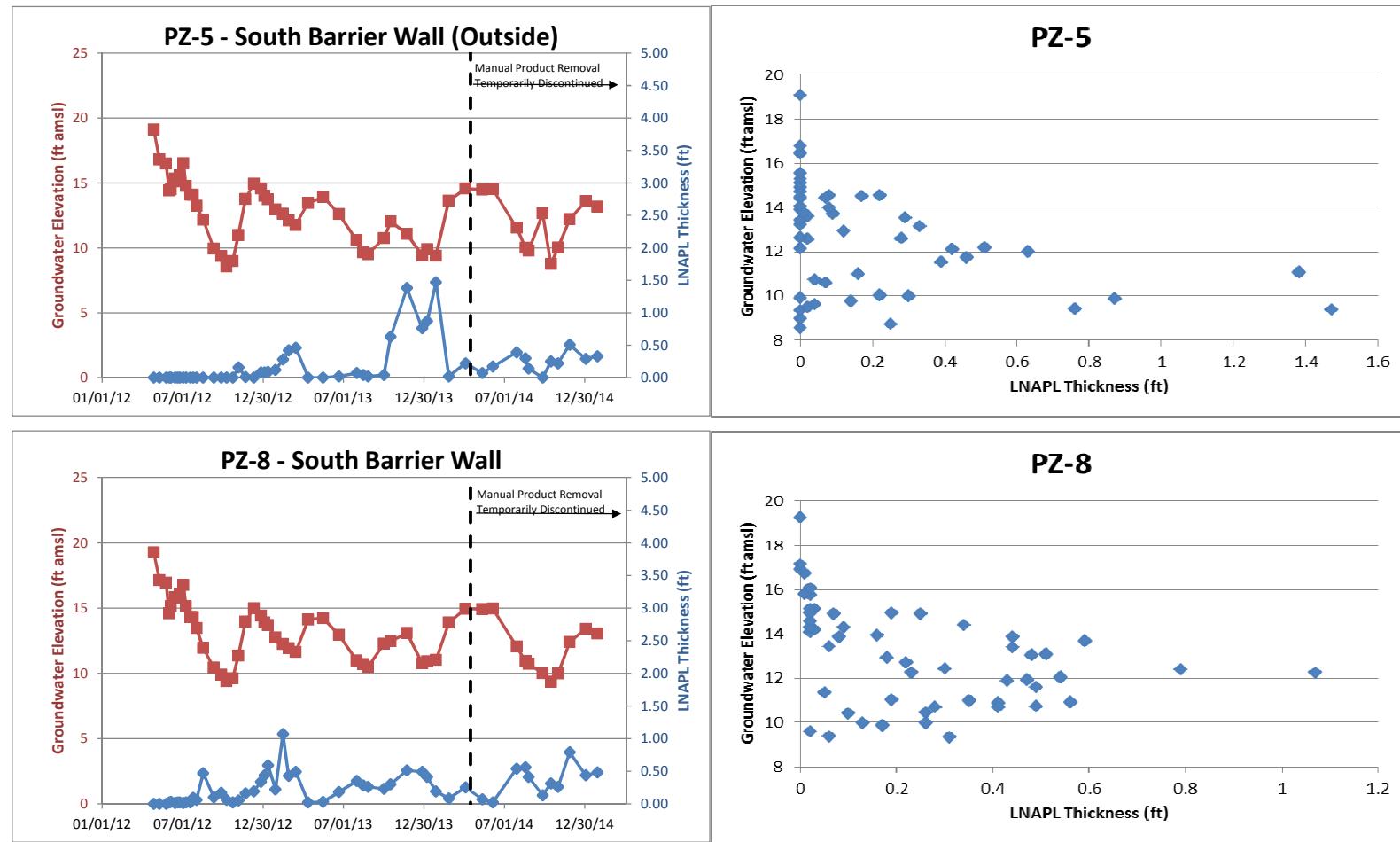


FIGURE E-2c
Groundwater and LNAPL Elevations - South End Barrier Wall
Kinder Morgan Liquids Terminals, Linnton Terminal

Average Transmissivity of NAPL in Barrier Wall Vicinity

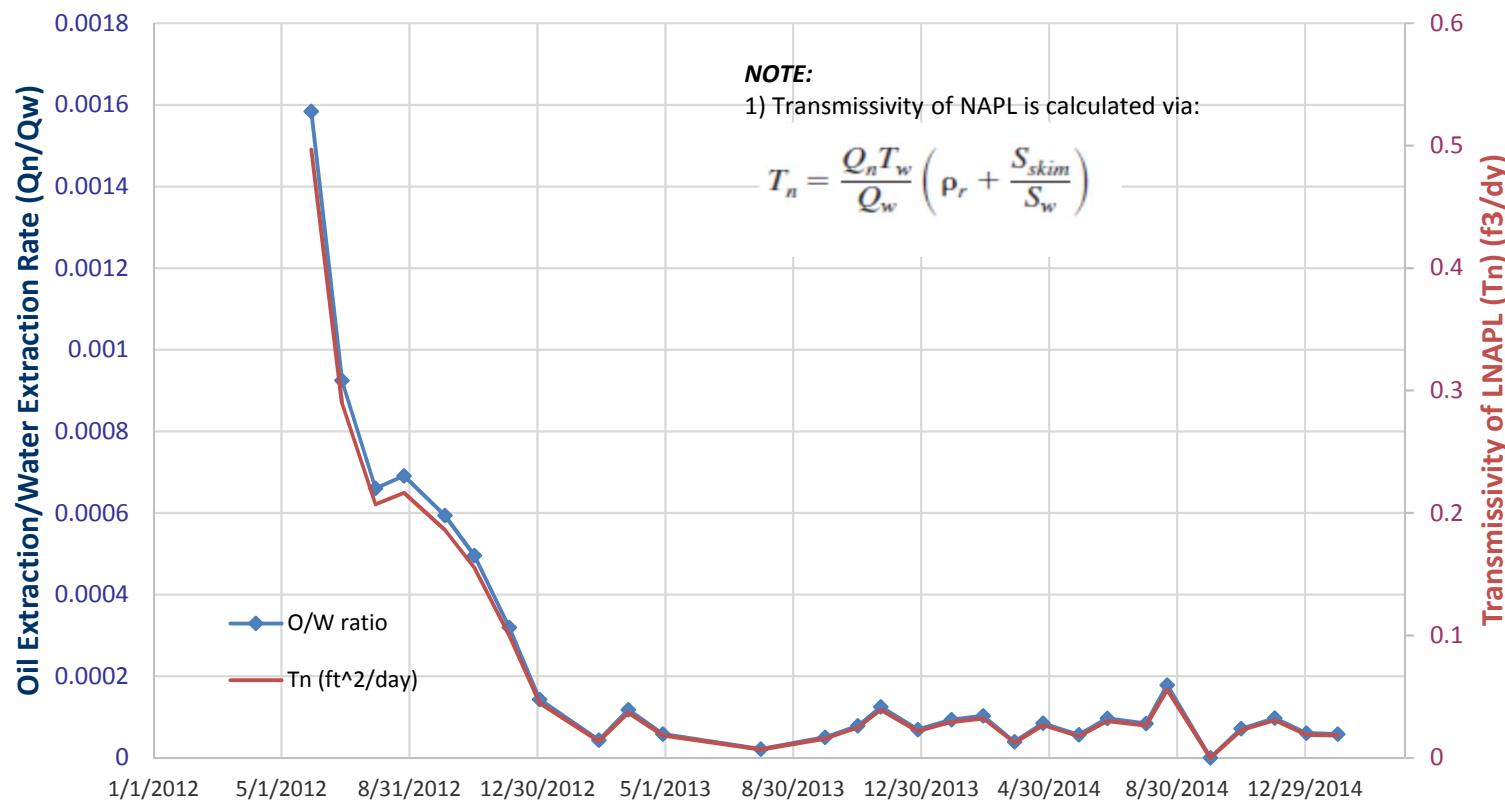


FIGURE E-3
LNAPL Transmissivity in Vicinity of Barrier Wall
Kinder Morgan Liquids Terminals, Linnton Terminal

Well Designation:

PZ-8
21-Apr-1

PZ-8 Baildown Testing

Ground Surface Elev (ft msl)	0.0
Top of Casing Elev (ft msl)	0.0
Well Casing Radius, r_c (ft):	0.083
Well Radius, r_w (ft):	0.417
LNAPL Specific Yield, S_y :	0.175
LNAPL Density Ratio, ρ_r :	0.850
Top of Screen (ft bgs):	15.0
Bottom of Screen (ft bgs):	25.0
LNAPL Baildown Vol. (gal.):	0.2
Effective Radius, r_{e3} (ft):	0.190
Effective Radius, r_{e2} (ft):	0.177
Initial Casing LNAPL Vol. (gal.):	0.06
Initial Filter LNAPL Vol. (gal.):	0.27

Enter These Data

r_{e1}

**Drawdown
Adjustment**
(ft)

LNAPL Transmissivity (ft²/day)

B&R C&J

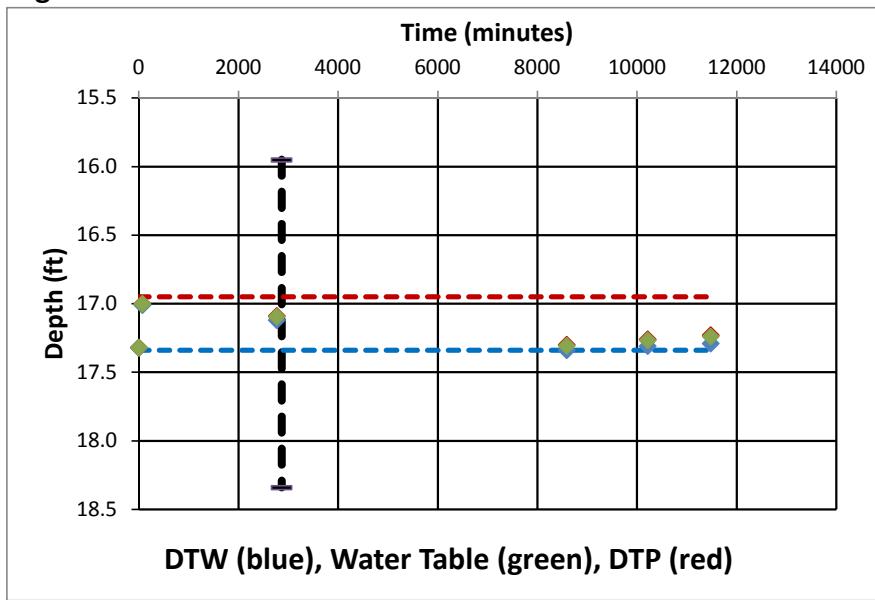
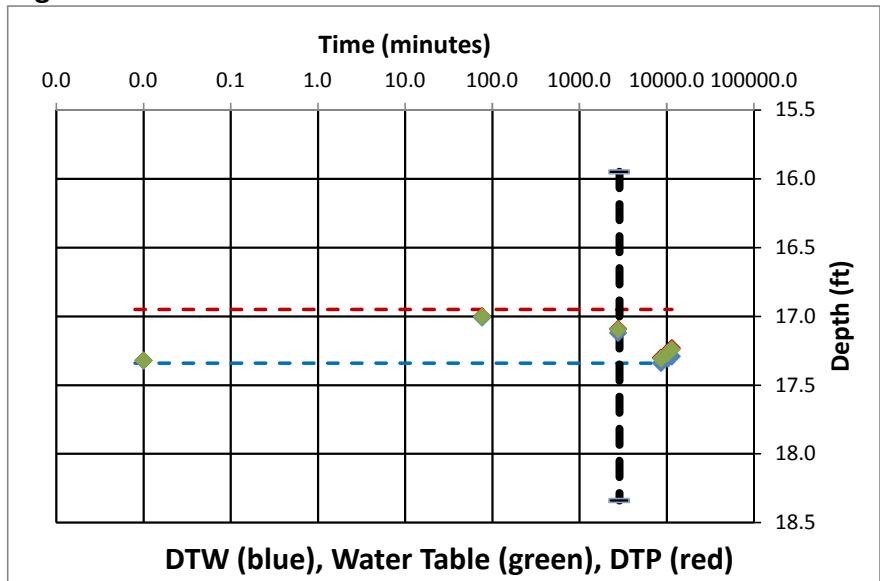
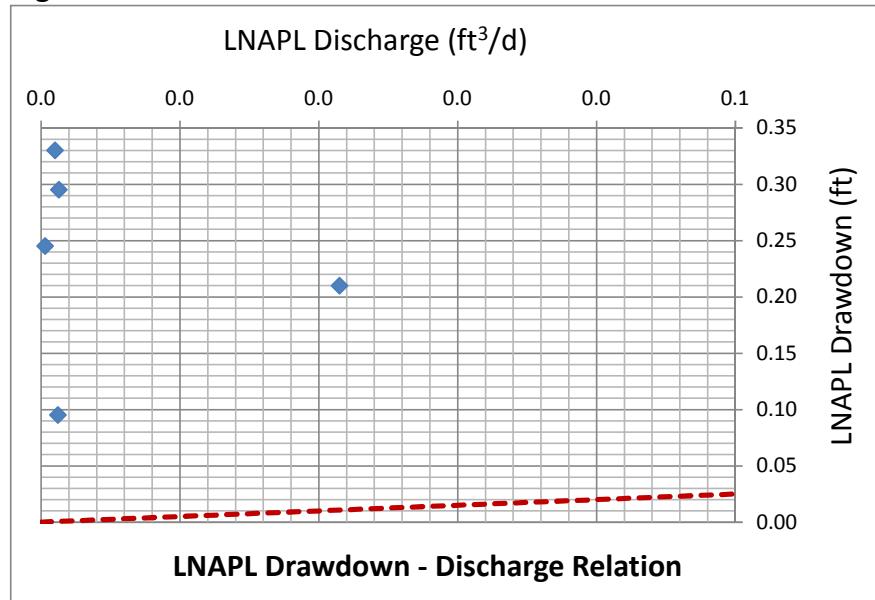
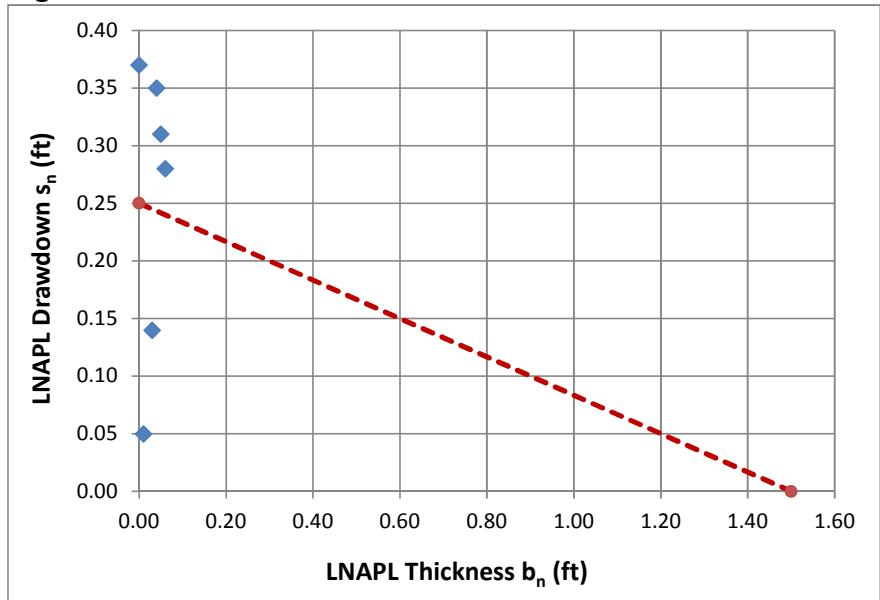
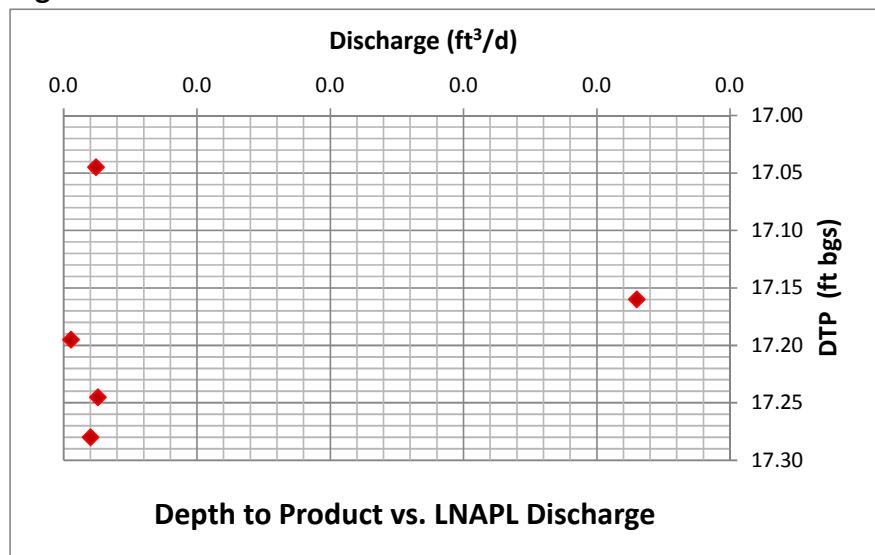
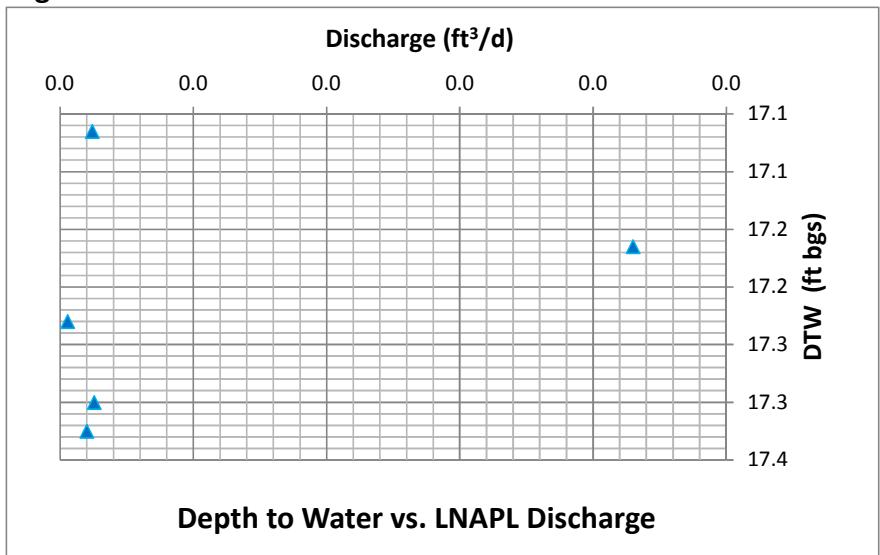
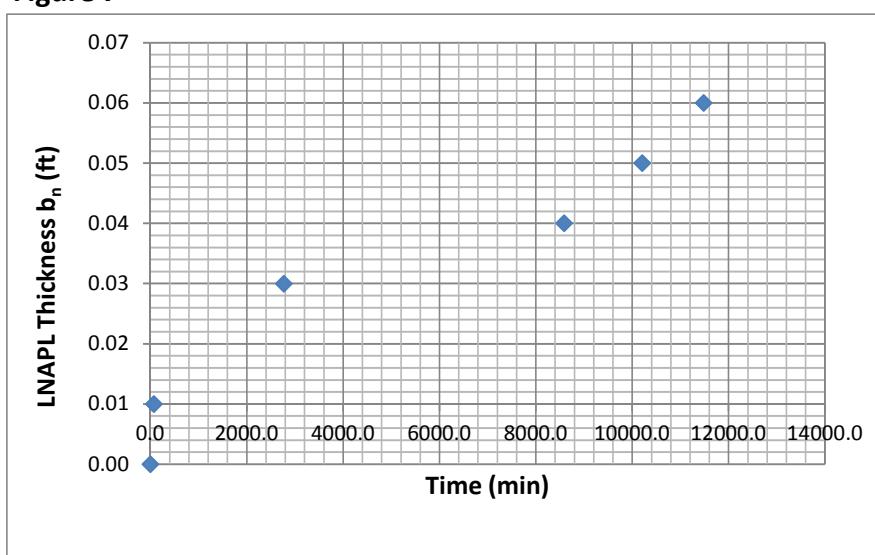
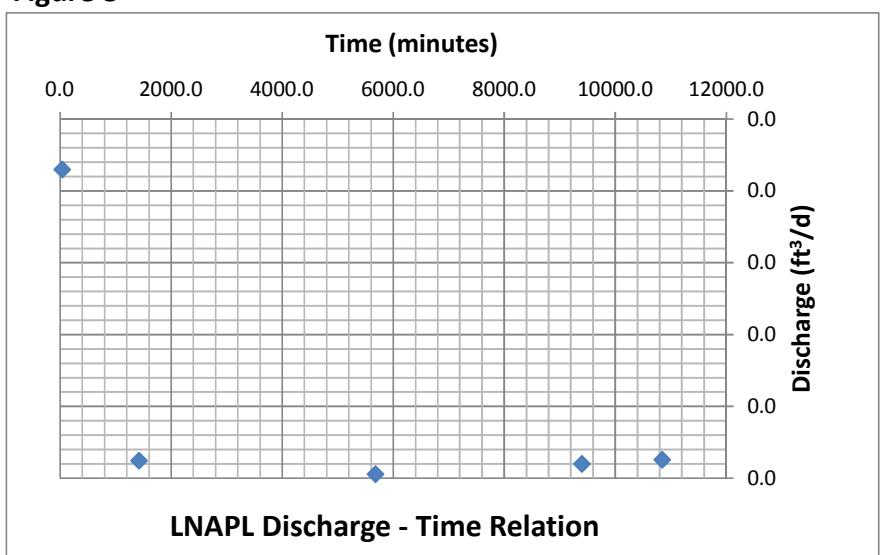
CB&P Average T

B&P Average

Calculated Parameters

Eff NAPL Well Vo Fract NAPL Removed

0.33 0.64

Figure 1**Figure 2****Figure 3****Figure 4****Figure 5****Figure 6****Figure 7****Figure 8**

Cooper and Jacob (1946)

Well Designation:	PZ-8
Date:	21-Apr-15

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	200	<- Enter or change values here
Time Adjustment (min):	200	

Trial S_n:

d <- Enter d for default or enter S_n value

Root-Mean-Square Error:

0.026 <- Minimize this using "Solver"

0.001 <- Working S_n

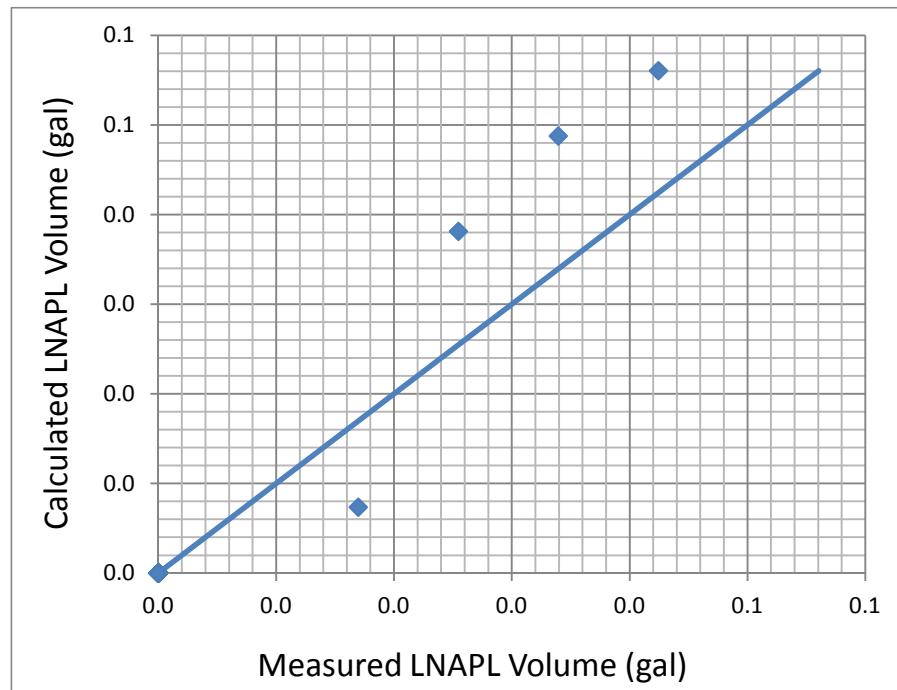
Trial T_n (ft²/d):

0.002 <- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result:

T_n (ft²/d) = 0.00



Cooper, Bredehoeft and Papadopoulos (1967)

Well Designation:	PZ-8
Date:	21-Apr-15

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	200	<- Enter or change values here
Initial Drawdown s _n (ft):	0.25	

Trial S_n: d <- Enter d for default

Root-Mean-Square Error: 1.818 <- Minimize this using "Solver"

Trial T_n (ft²/d): 0.090 <- By changing T_n through "Solver"

0.008 <- Working S_n

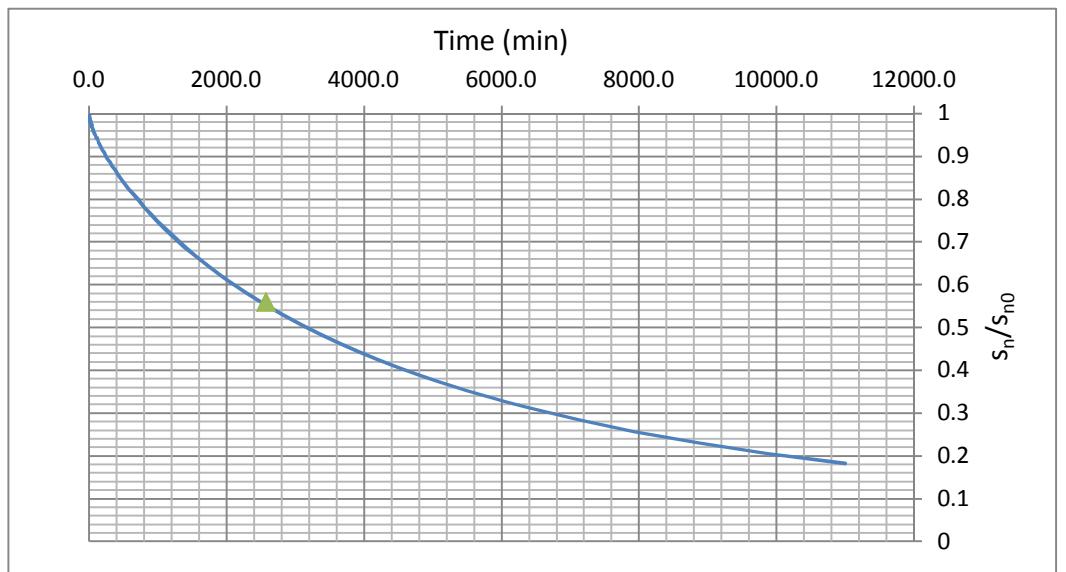
Add constraint Tn > 0.00001

Model Result:

T_n (ft²/d) =

0.09

T _{min}	0.2
T _{max}	11000



Well Designation:
Date:

PZ-3
21-Apr-15

PZ-3 Baildown Testing

Ground Surface Elev (ft msl)	0.0
Top of Casing Elev (ft msl)	0.0
Well Casing Radius, r_c (ft):	0.083
Well Radius, r_w (ft):	0.417
LNAPL Specific Yield, S_y :	0.175
LNAPL Density Ratio, ρ_r :	0.909
Top of Screen (ft bgs):	15.0
Bottom of Screen (ft bgs):	25.0
LNAPL Baildown Vol. (gal.):	1.1
Effective Radius, r_{e3} (ft):	0.190
Effective Radius, r_{e2} (ft):	0.098
Initial Casing LNAPL Vol. (gal.):	0.21
Initial Filter LNAPL Vol. (gal.):	0.90

Enter These Data

Drawdown
Adjustment
(ft)
0

r_{e1}

LNAPL Transmissivity (ft²/day)

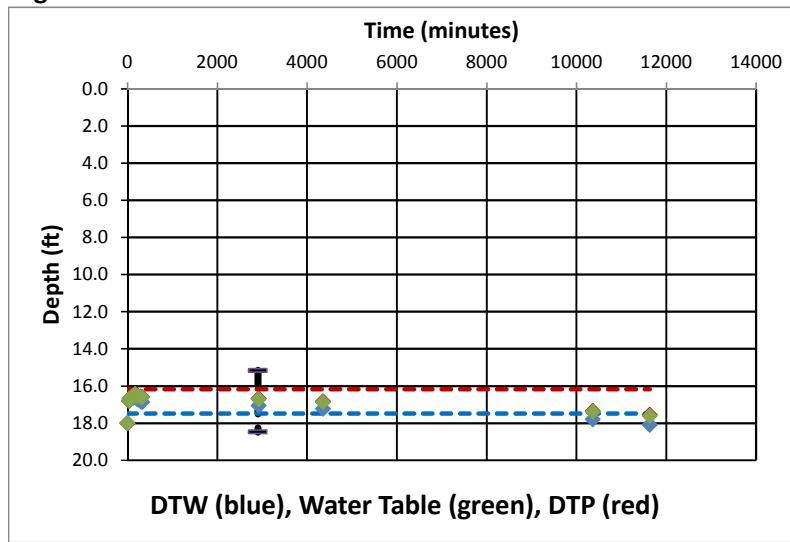
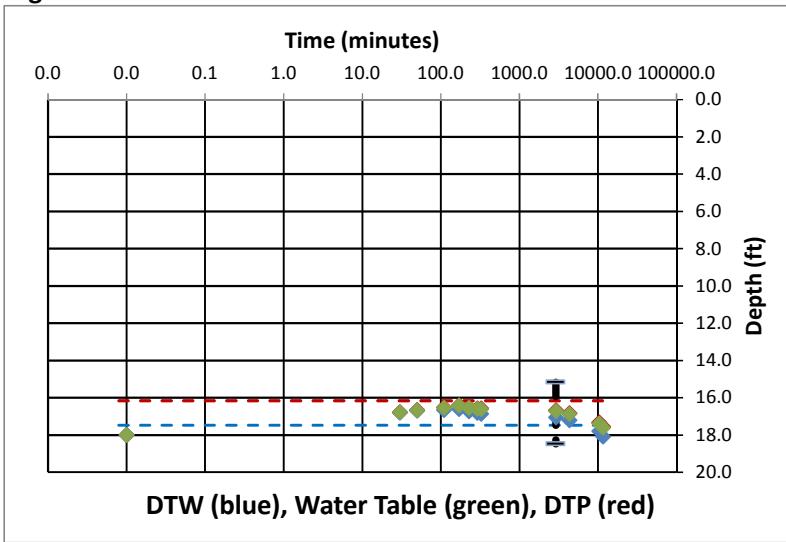
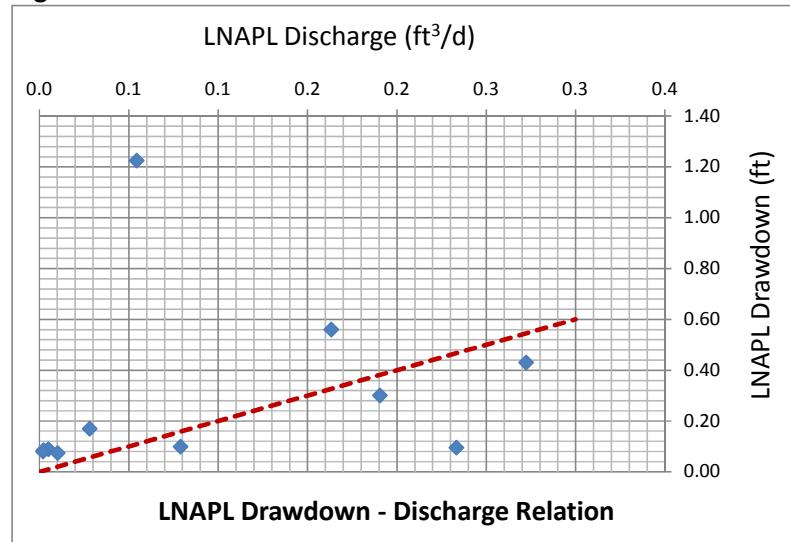
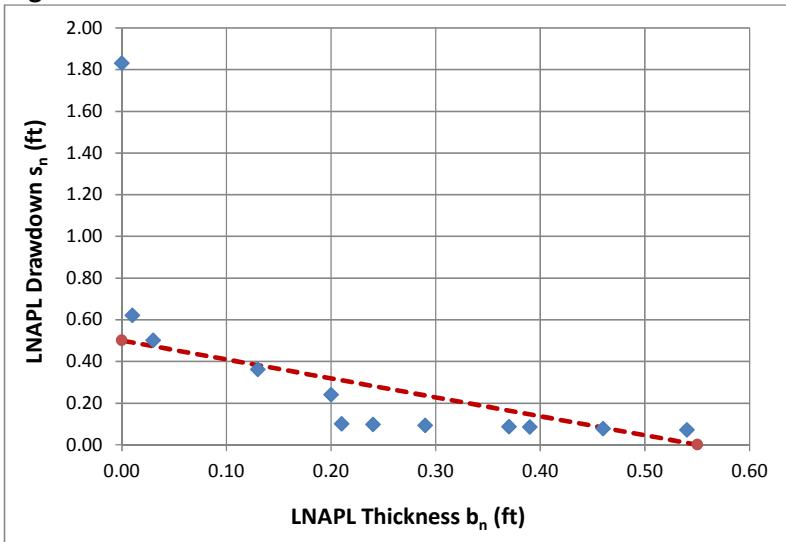
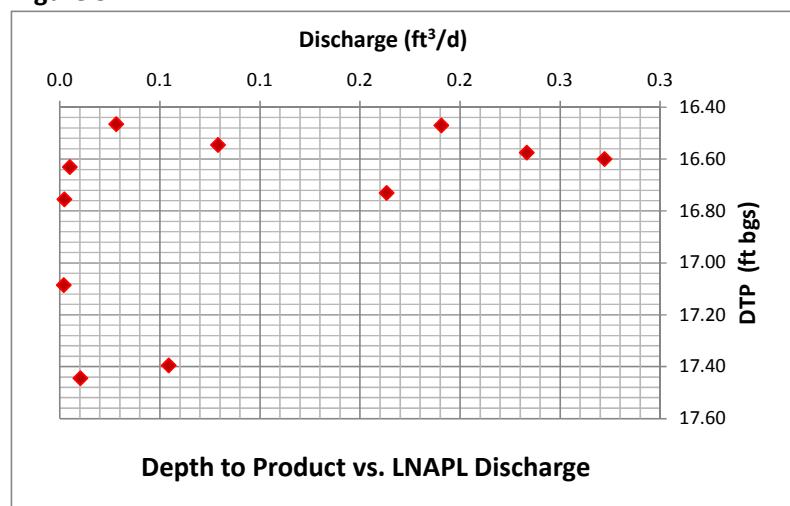
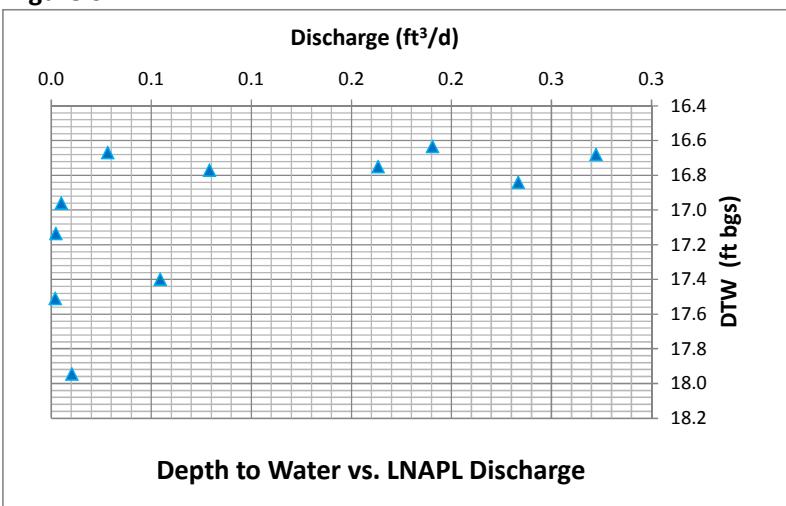
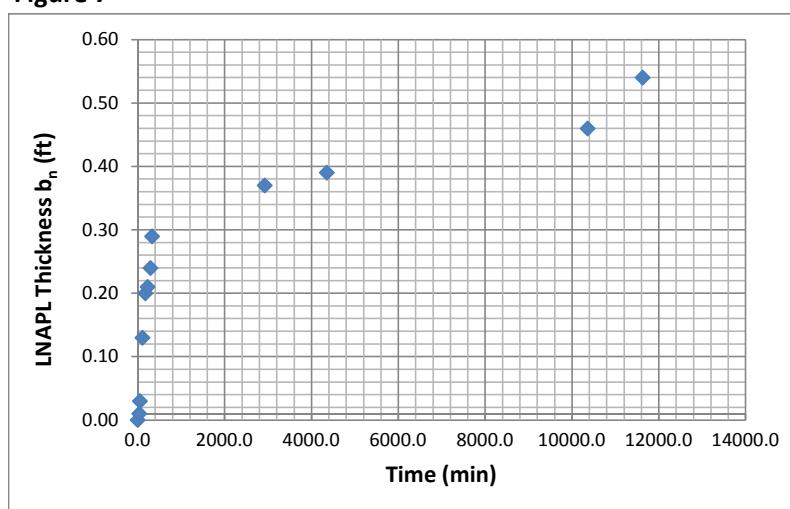
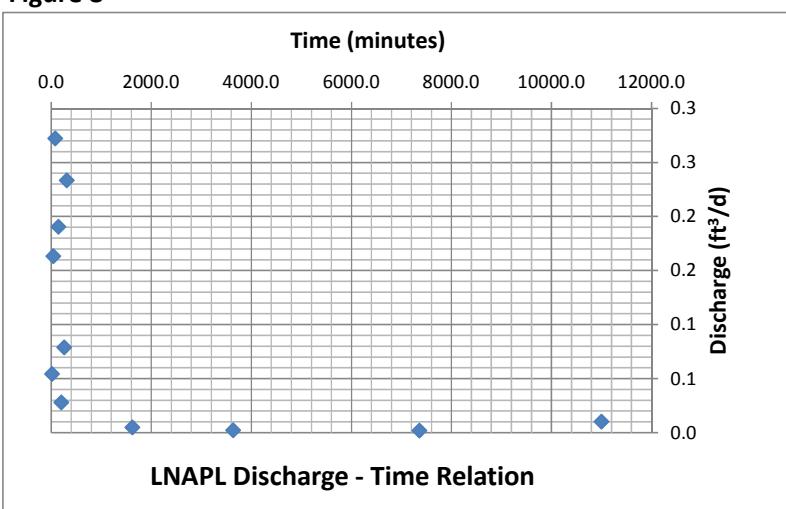
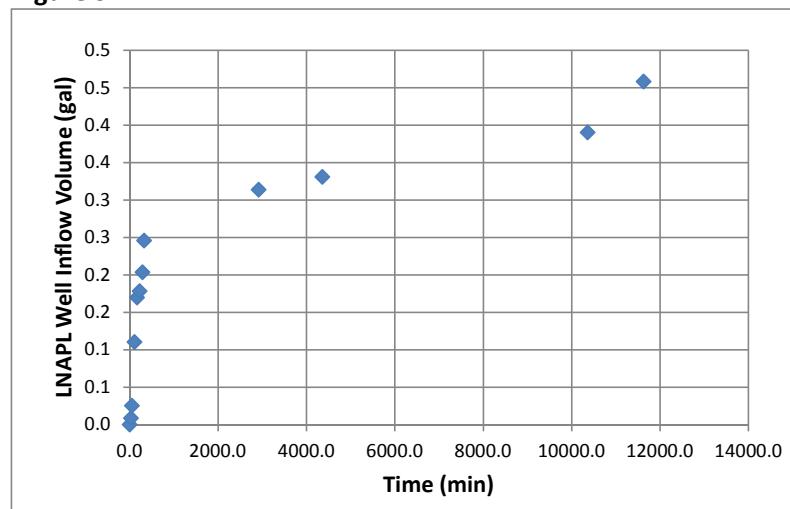
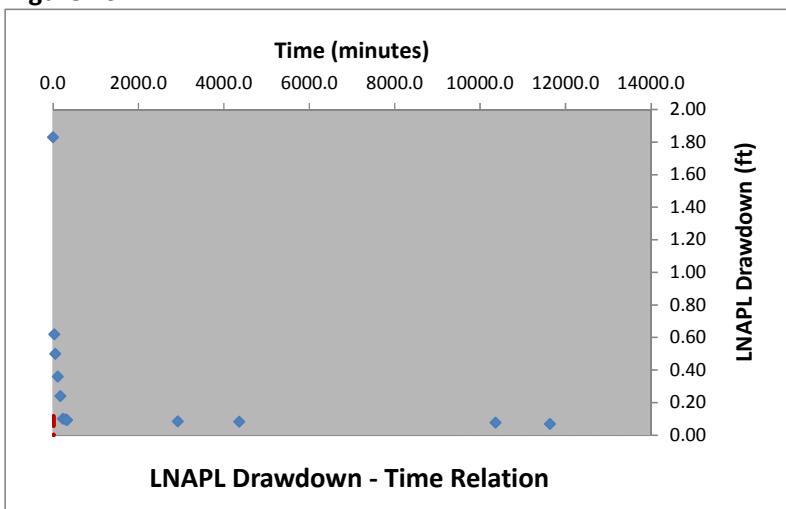
B&R	C&J	CB&P	Average T
0.00	0.03	0.00	0.01

Calculated Parameters

Eff NAPL Well Vo Fract NAPL Removed

1.11 1.02

Date and Time	Enter Data Here					Water Table Depth (ft)	LNAPL Drawdown s_n (ft)	LNAPL				
	Time (min)	DTP (ft btoc)	DTW (ft btoc)	DTP (ft bgs)	DTW (ft bgs)			Average Time (min)	Discharge Q_n (ft ³ /d)	s_n (ft)	b_n (ft)	r_e (ft)
		0	16.17	17.48	16.17							
4/21/15 9:30						16.29						
4/21/15 10:10	0.0	18.00	18.00	18.00	18.00		18.00	1.83				0.00
4/21/15 10:40	30.0	16.79	16.80	16.79	16.80		16.79	0.62	15.0	0.054	1.23	0.01 0.190
4/21/15 11:00	50.0	16.67	16.70	16.67	16.70		16.67	0.50	40.0	0.163	0.56	0.03 0.190
4/21/15 12:00	110.0	16.53	16.66	16.53	16.66		16.54	0.36	80.0	0.272	0.43	0.13 0.190
4/21/15 13:00	170.0	16.41	16.61	16.41	16.61		16.43	0.24	140.0	0.191	0.30	0.20 0.190
4/21/15 13:58	228.0	16.52	16.73	16.52	16.73		16.54	0.10	199.0	0.028	0.17	0.21 0.190
4/21/15 15:00	290.0	16.57	16.81	16.57	16.81		16.59	0.10	259.0	0.079	0.10	0.24 0.190
4/21/15 15:35	325.0	16.58	16.87	16.58	16.87		16.61	0.09	307.5	0.233	0.10	0.29 0.190
4/23/15 10:50	2920.0	16.68	17.05	16.68	17.05		16.71	0.09	1622.5	0.005	0.09	0.37 0.190
4/24/15 10:45	4355.0	16.83	17.22	16.83	17.22		16.87	0.08	3637.5	0.002	0.08	0.39 0.190
4/28/15 14:50	10360.0	17.34	17.80	17.34	17.80		17.38	0.08	7357.5	0.002	0.08	0.46 0.190
4/21/15 10:15	42123.5	11630.0	17.55	18.09	17.55	18.09	17.60	0.07	10995.0	0.010	0.07	0.54 0.190
4/21/15 10:20				#N/A	#N/A		#N/A	#N/A	0.0	#N/A	#N/A	#N/A 0.000
				#N/A	#N/A		#N/A	#N/A	0.0	#N/A	#N/A	#N/A 0.000

Figure 1**Figure 2****Figure 3****Figure 4****Figure 5****Figure 6****Figure 7****Figure 8****Figure 9****Figure 10**

Generalized Bouwer and Rice (1976)

Well Designation:	PZ-3
Date:	21-Apr-15

$$T_n = \frac{r_e^2 \ln(R/r_e) \ln(s_n(t_1)/s_n(t))}{2(-J)(t - t_1)}$$

Enter early time cut-off for least-squares model fit

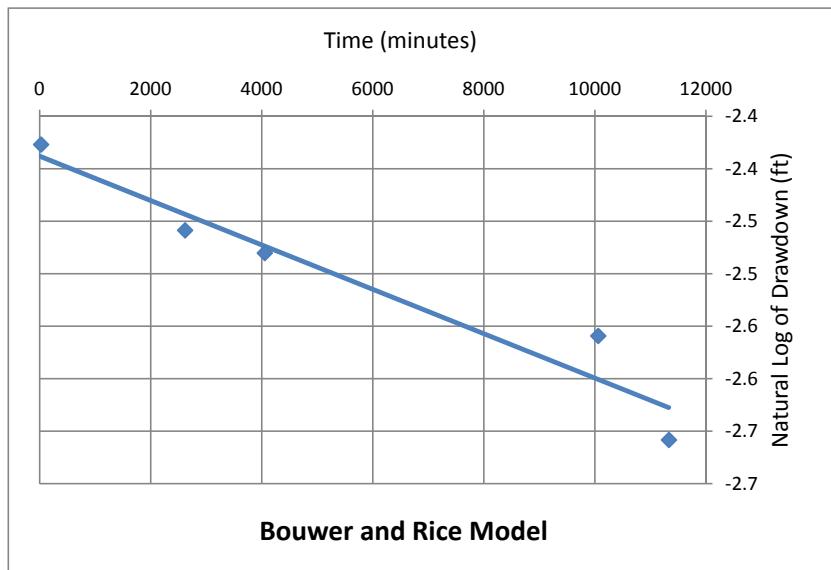
Time_{cut} <- Enter or change value here

Model Results: $T_n (\text{ft}^2/\text{d}) = 0.001$ $+/- 0.00$ ft^2/d

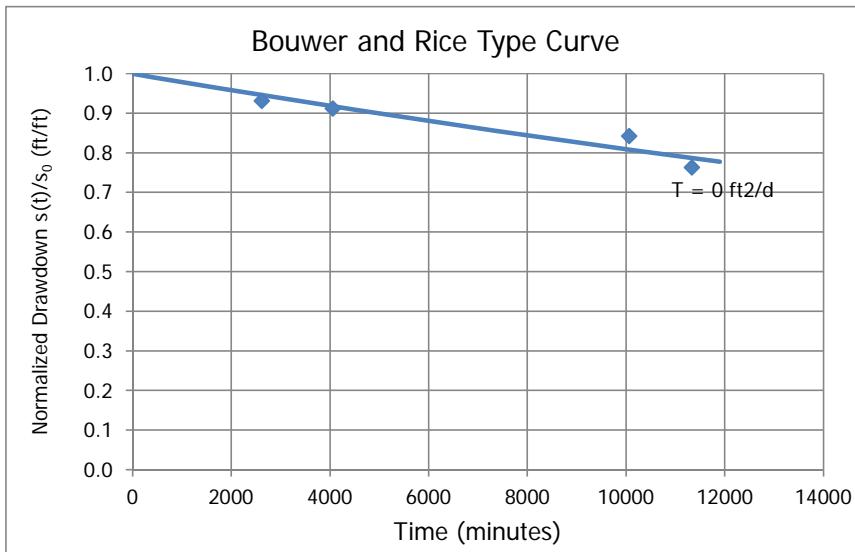
L _e /r _e	6.9
C	1.07
R/r _e	3.98

J-Ratio
-0.909

Coef. Of Variation
0.15



C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



Cooper and Jacob (1946)

Well Designation:	PZ-3
Date:	21-Apr-15

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	300	<- Enter or change values here
Time Adjustment (min):	300	

Trial S_n: <- Enter d for default or enter S_n value

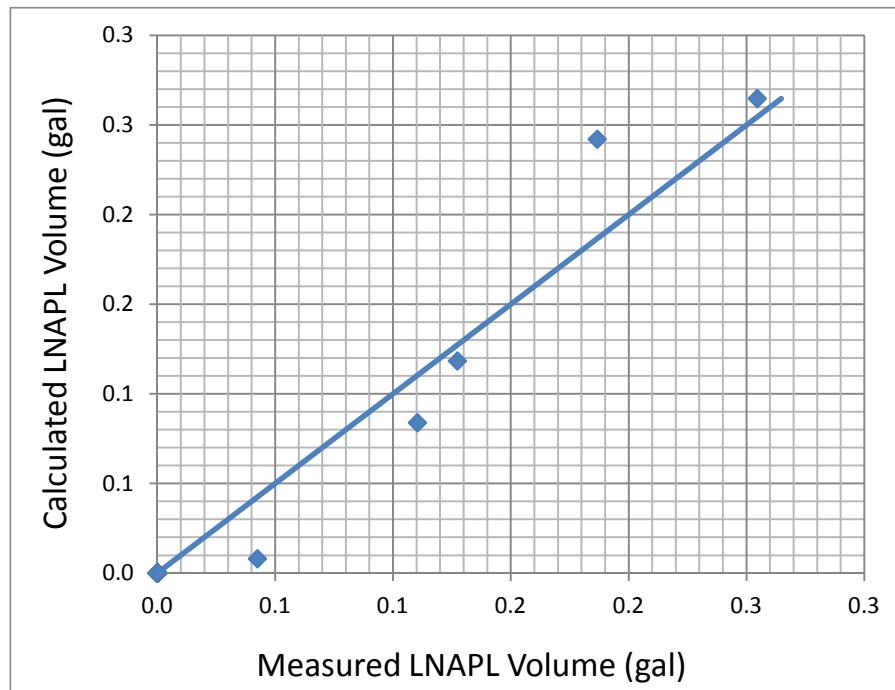
Root-Mean-Square Error: <- Minimize this using "Solver"

Working S_n:

Trial T_n (ft²/d): <- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result: $T_n (\text{ft}^2/\text{d}) = 0.03$



Cooper, Bredehoeft and Papadopoulos (1967)

Well Designation:	PZ-3
Date:	21-Apr-15

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	300	<- Enter or change values here
Initial Drawdown s _n (ft):	0.1	

Trial S_n: d <- Enter d for default

Root-Mean-Square Error: 0.102 <- Minimize this using "Solver"

Trial T_n (ft²/d): 0.003 <- By changing T_n through "Solver"

0.001 <- Working S_n

Add constraint Tn > 0.00001

Model Result:

T_n (ft²/d) =

0.00

T _{min}	0.2
T _{max}	11000

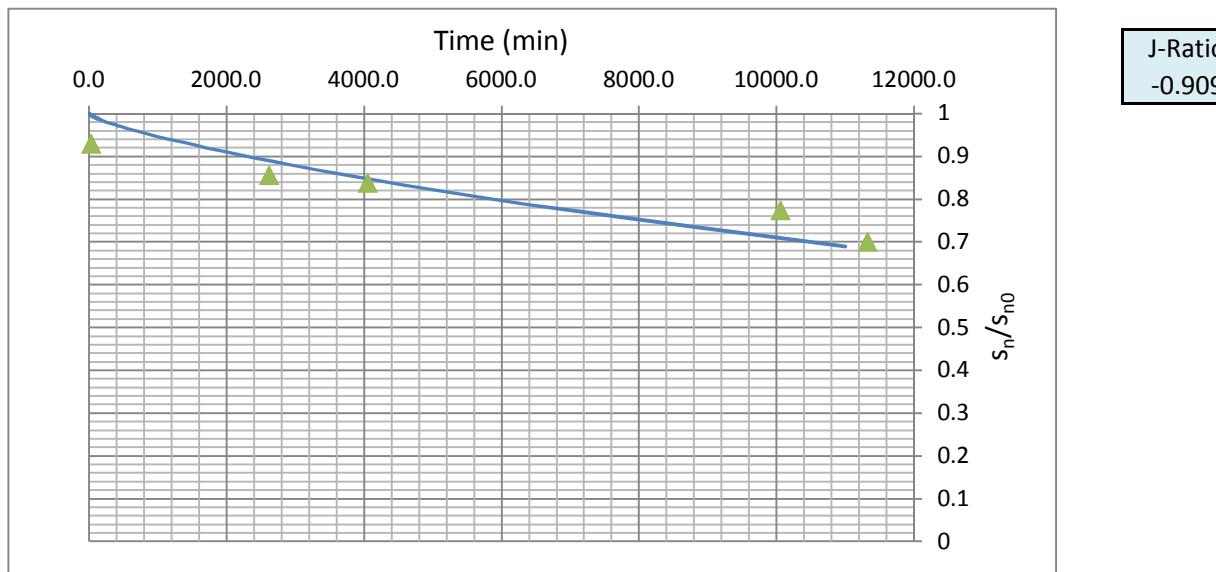
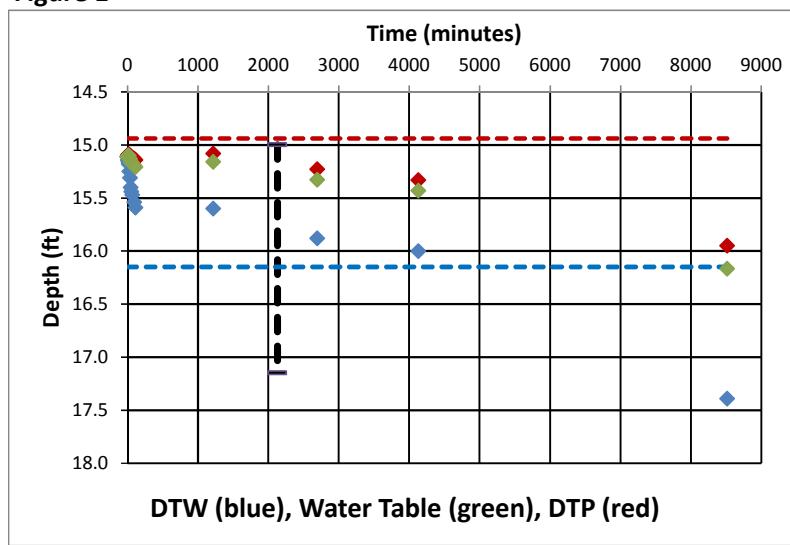
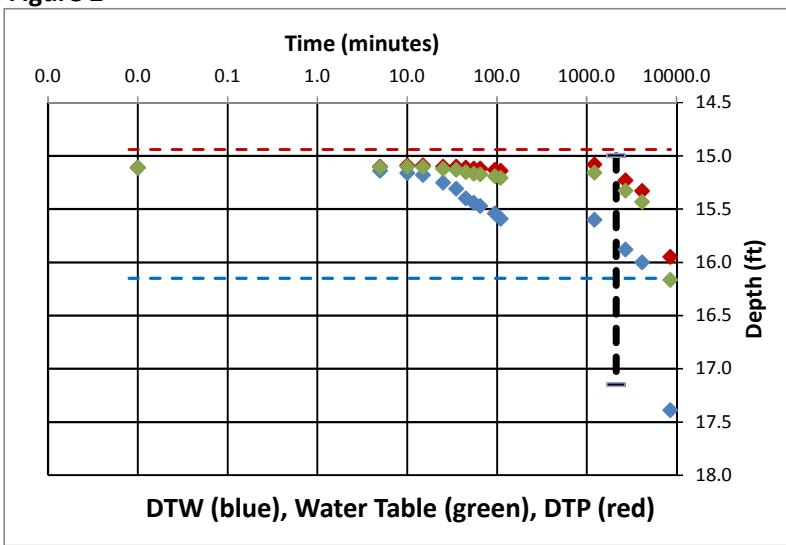
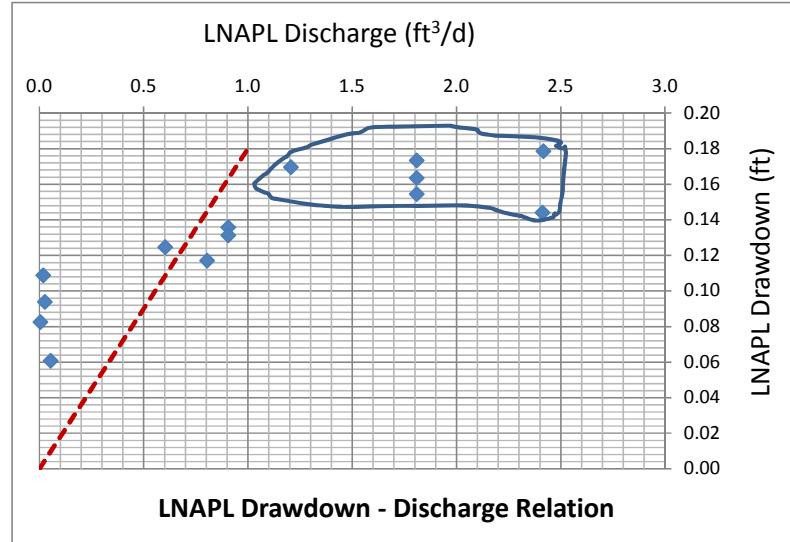
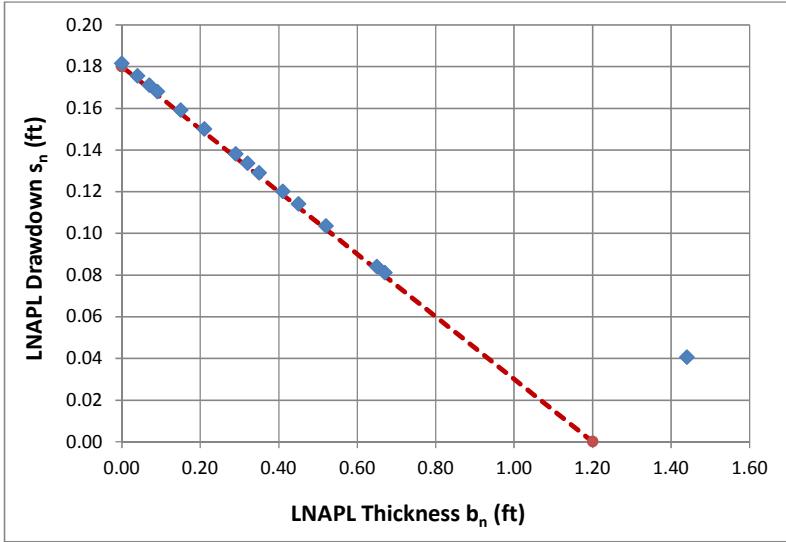
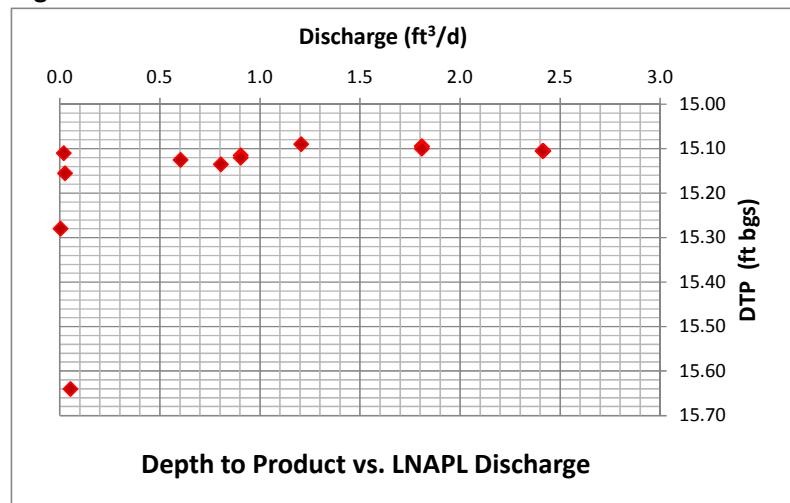
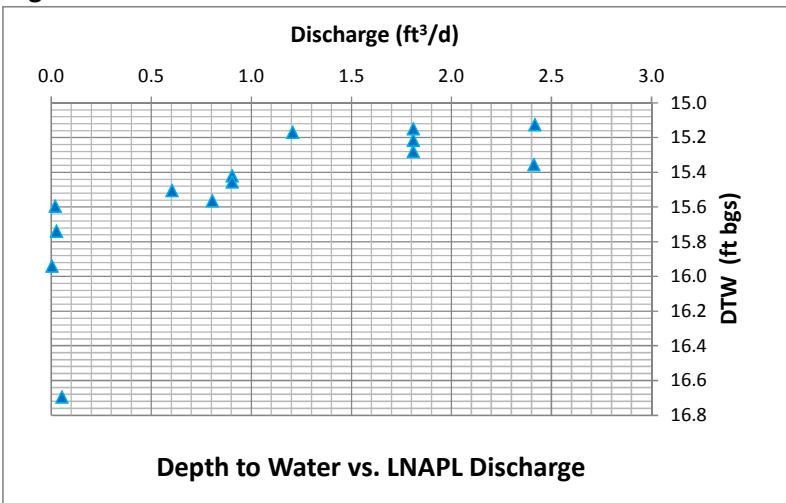
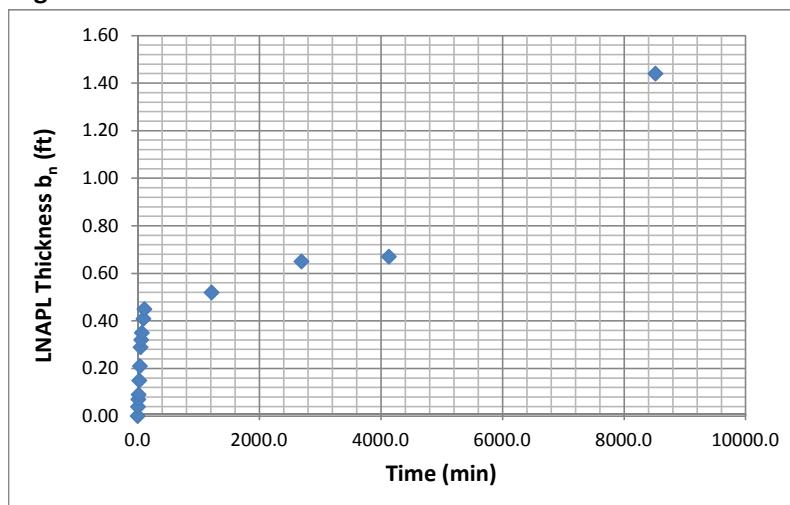
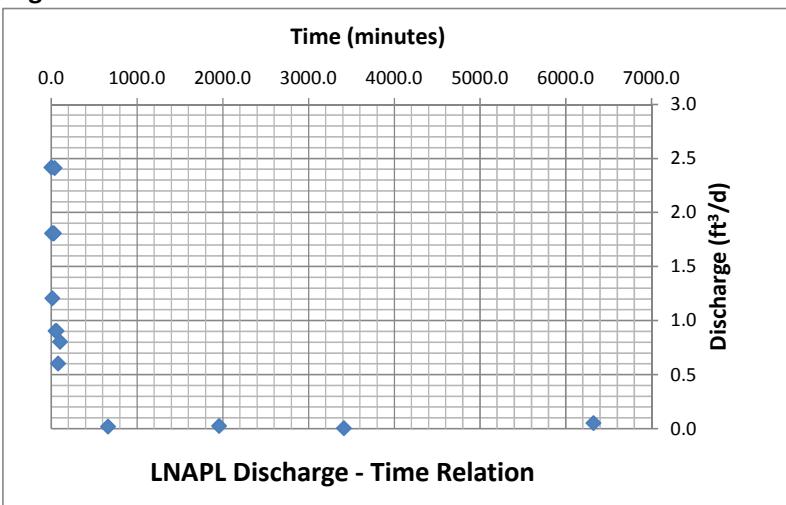
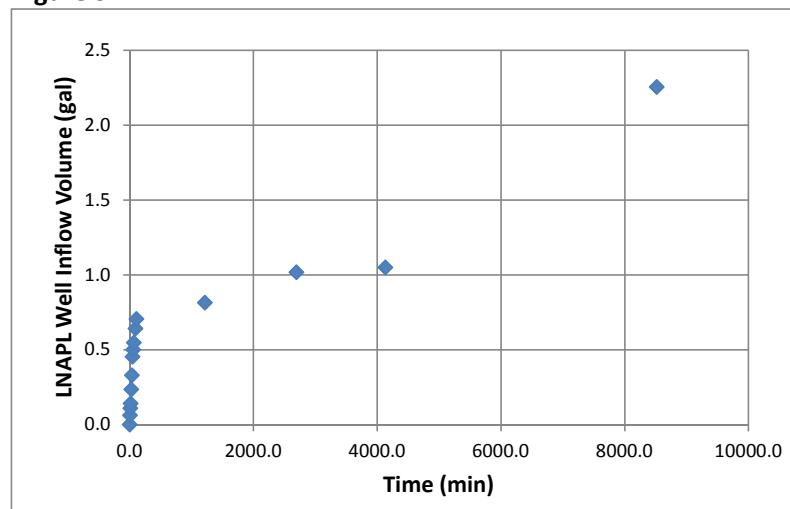
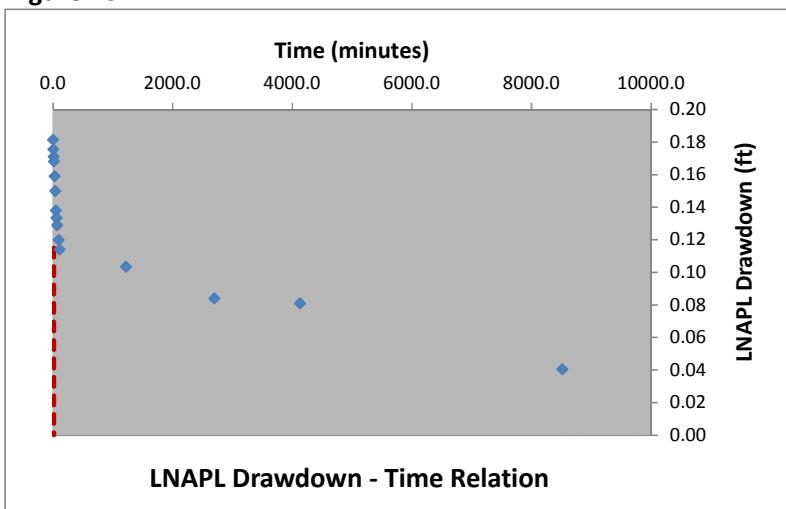


Figure 1**Figure 2****Figure 3****Figure 4****Figure 5****Figure 6****Figure 7****Figure 8****Figure 9****Figure 10**

Generalized Bouwer and Rice (1976)

Well Designation: EW-6
Date: 21-Apr-15

$$T_n = \frac{r_e^2 \ln(R/r_e) \ln(s_n(t_1)/s_n(t))}{2(-J)(t - t_1)}$$

Enter early time cut-off for least-squares model fit

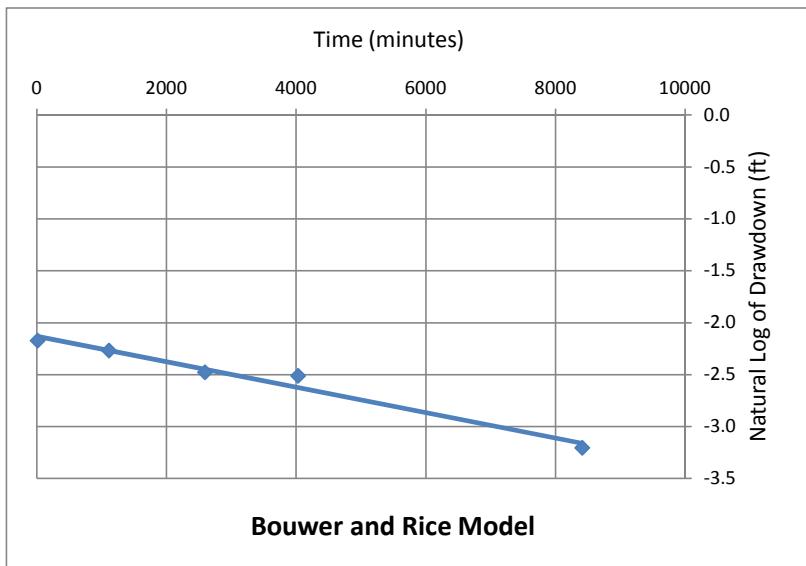
Time_{cut} <- Enter or change value here

Model Results: $T_n (\text{ft}^2/\text{d}) = 0.04$ +/- ft^2/d

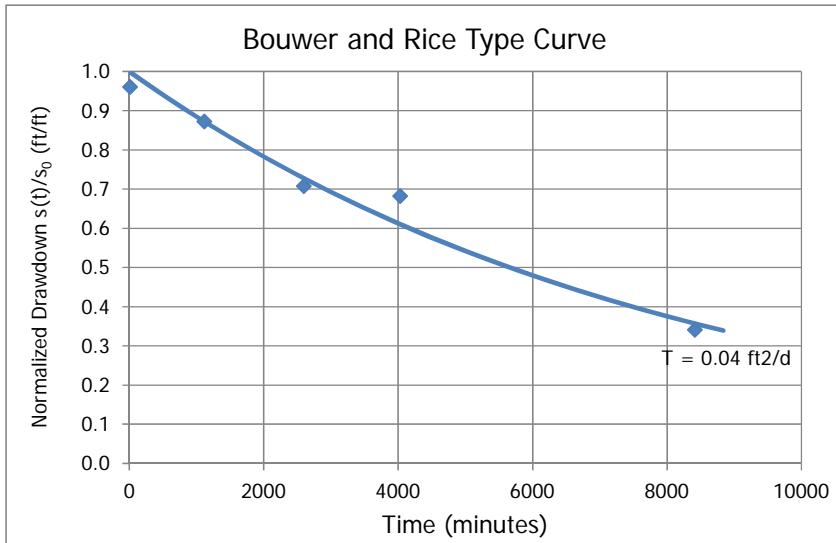
L_e/r_e
4.5
C
0.97
R/r_e
2.85

J-Ratio
-0.150

Coef. Of Variation
0.09



C coefficient calculated from Eq. 6.5(c) of Butler, The Design, Performance, and Analysis of Slug Tests, CRC Press, 2000.



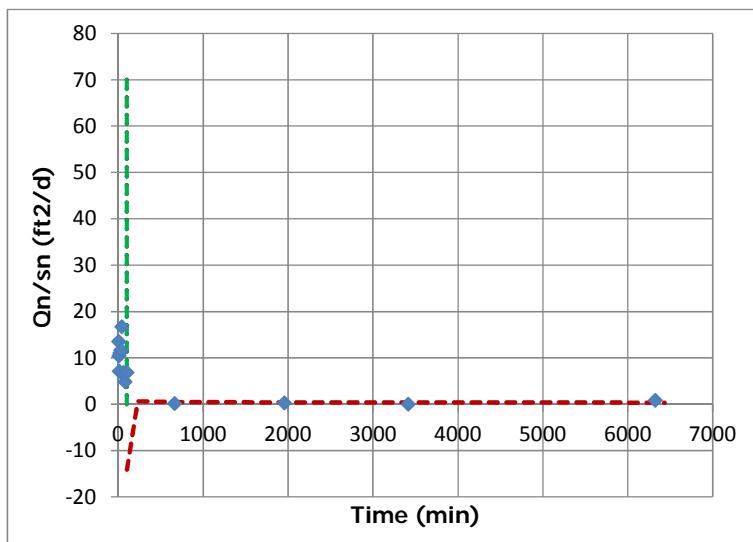
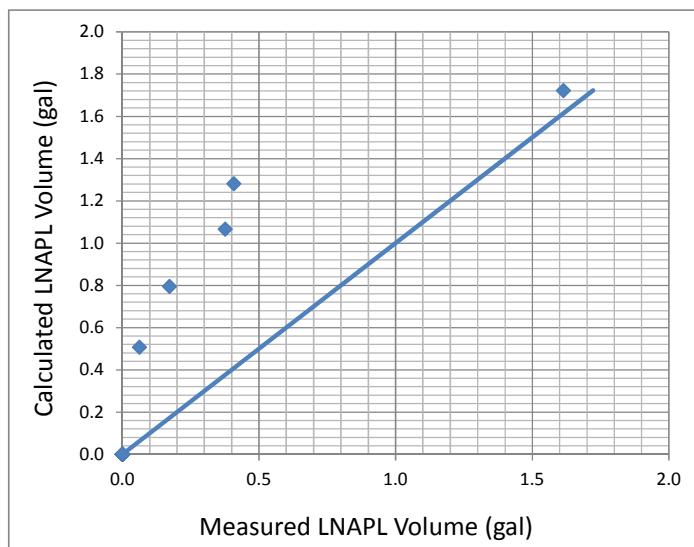
Cooper and Jacob (1946)

 Well Designation: EW-6
 Date: 21-Apr-15

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n S_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	100	<- Enter or change values here
Time Adjustment (min):	100	
Trial S _n :	d	<- Enter d for default or enter S _n value
Root-Mean-Square Error:	1.355	<- Minimize this using "Solver"
	0.011	<- Working S _n
Trial T _n (ft ² /d):	0.200	<- By changing T _n through "Solver"
Add constraint T _n > 0.00001		
Model Result:	T_n (ft²/d) = 0.20	



Cooper, Bredehoeft and Papadopoulos (1967)

Well Designation:	EW-6
Date:	21-Apr-15

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	100	<- Enter or change values here
Initial Drawdown s _n (ft):	0.11	

Trial S_n: d <- Enter d for default

Root-Mean-Square Error: 0.190 <- Minimize this using "Solver"

Trial T_n (ft²/d): 0.090 <- By changing T_n through "Solver"

0.008 <- Working S_n

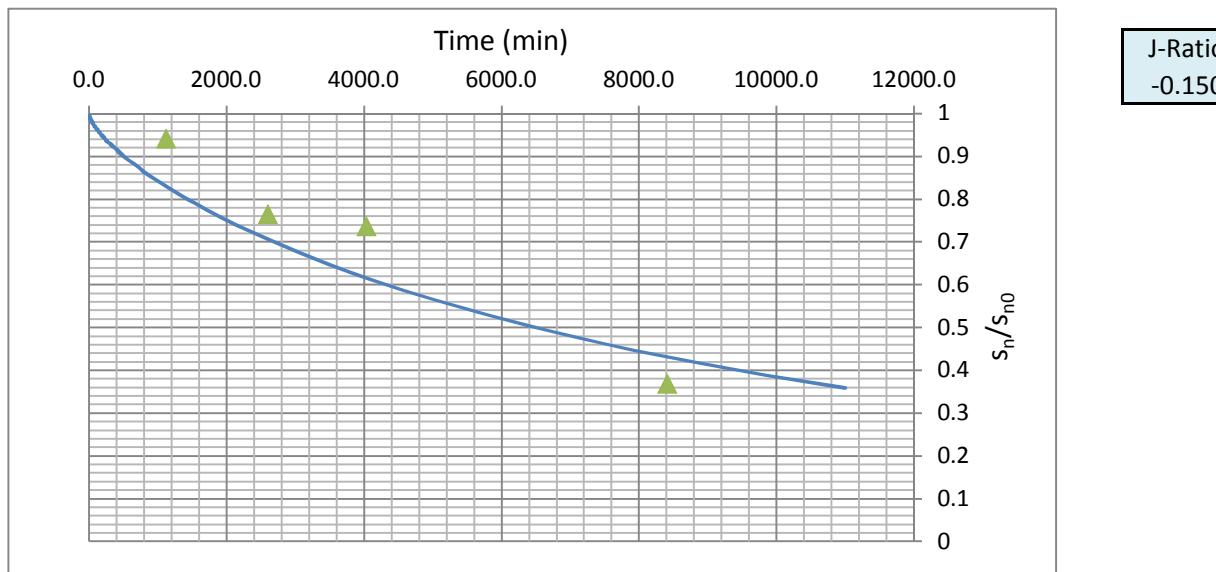
Add constraint Tn > 0.00001

Model Result:

T_n (ft²/d) =

0.09

T _{min}	0.2
T _{max}	11000



Well Designation:

EW-6

EW-6 Baildown Testing

Date:

21-Apr-15

Ground Surface Elev (ft msl)	0.0
Top of Casing Elev (ft msl)	0.0
Well Casing Radius, r_c (ft):	0.167
Well Radius, r_w (ft):	0.500
LNAPL Specific Yield, S_y :	0.175
LNAPL Density Ratio, ρ_f :	0.850
Top of Screen (ft bgs):	15.0
Bottom of Screen (ft bgs):	30.0
LNAPL Baildown Vol. (gal.):	1.6
Effective Radius, r_{e3} (ft):	0.258
Effective Radius, r_{e2} (ft):	0.247
Initial Casing LNAPL Vol. (gal.):	0.79
Initial Filter LNAPL Vol. (gal.):	1.05

Enter These Data

 r_{e1}

Drawdown
Adjustment
(ft)

LNAPL Transmissivity (ft²/day)

B&R C&J

CB&P Average T

0.04 0.20

0.09 0.11

Calculated Parameters

Eff NAPL Well Vo Fract NAPL Removed

1.84 0.87

Date and Time	Enter Data Here			Water Table Depth (ft)	LNAPL Drawdown s_n (ft)	LNAPL				
	Time (min)	DTP (ft btoc)	DTW (ft btoc)			Average Time (min)	Discharge Q_n (ft ³ /d)	s_n (ft)	b_n (ft)	r_e (ft)
4/21/15 13:10	0	14.94	16.15	14.94	16.15	15.12				1.21
4/21/15 13:55	0.0	15.11	15.11	15.11	15.11	15.11	0.18			0.00
4/21/15 14:00	5.0	15.10	15.14	15.10	15.14	15.11	0.18	2.5	2.418	0.18
4/21/15 14:05	10.0	15.09	15.16	15.09	15.16	15.10	0.17	7.5	1.810	0.17
4/21/15 14:10	15.0	15.09	15.18	15.09	15.18	15.10	0.17	12.5	1.206	0.17
4/21/15 14:20	25.0	15.10	15.25	15.10	15.25	15.12	0.16	20.0	1.810	0.16
4/21/15 14:30	35.0	15.10	15.31	15.10	15.31	15.13	0.15	30.0	1.810	0.15
4/21/15 14:40	45.0	15.11	15.40	15.11	15.40	15.15	0.14	40.0	2.413	0.14
4/21/15 14:50	55.0	15.12	15.44	15.12	15.44	15.17	0.13	50.0	0.905	0.14
4/21/15 15:00	65.0	15.12	15.47	15.12	15.47	15.17	0.13	60.0	0.905	0.13
4/21/15 15:30	95.0	15.13	15.54	15.13	15.54	15.19	0.12	80.0	0.603	0.12
4/21/15 15:45	110.0	15.14	15.59	15.14	15.59	15.21	0.11	102.5	0.804	0.12
4/22/15 10:10	1215.0	15.08	15.60	15.08	15.60	15.16	0.10	662.5	0.019	0.11
4/23/15 10:50	2695.0	15.23	15.88	15.23	15.88	15.33	0.08	1955.0	0.026	0.09
4/24/15 10:45	4130.0	15.33	16.00	15.33	16.00	15.43	0.08	3412.5	0.004	0.08
4/27/15 11:50	8515.0	15.95	17.39	15.95	17.39	16.17	0.04	6322.5	0.053	0.06

Well Designation:
Date:

EW-1
21-Apr-15

Ground Surface Elev (ft msl)	0.0
Top of Casing Elev (ft msl)	0.0
Well Casing Radius, r_c (ft):	0.250
Well Radius, r_w (ft):	0.500
LNAPL Specific Yield, S_y :	0.175
LNAPL Density Ratio, ρ_r :	0.909
Top of Screen (ft bgs):	16.0
Bottom of Screen (ft bgs):	31.0
LNAPL Baildown Vol. (gal.):	2.3
Effective Radius, r_{e3} (ft):	0.309
Effective Radius, r_{e2} (ft):	0.304
Initial Casing LNAPL Vol. (gal.):	2.47
Initial Filter LNAPL Vol. (gal.):	-1.23

Enter These Data

Drawdown
Adjustment

(ft)

0

LNAPL Transmissivity (ft²/day)

B&R

C&J

CB&P

Average T

NA

0.10

0.09

0.10

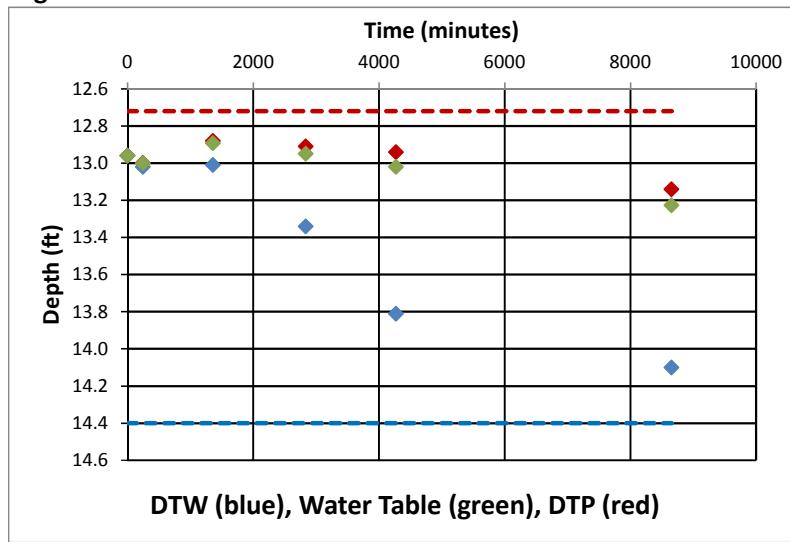
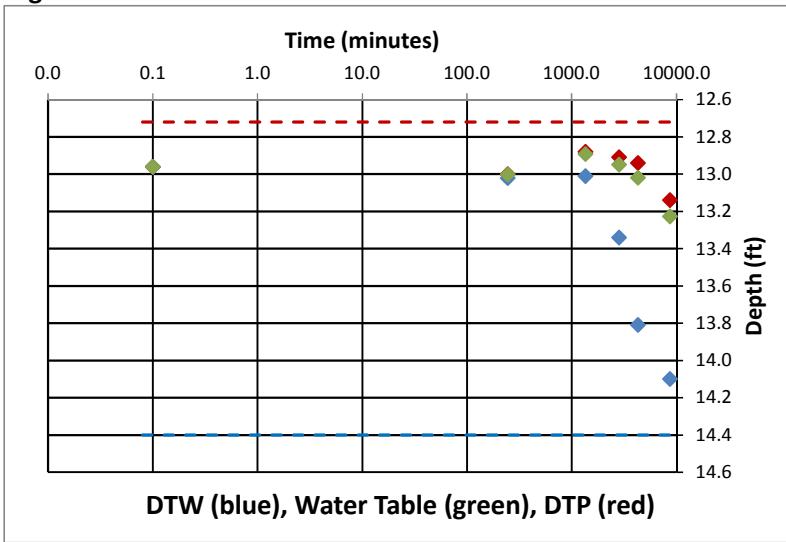
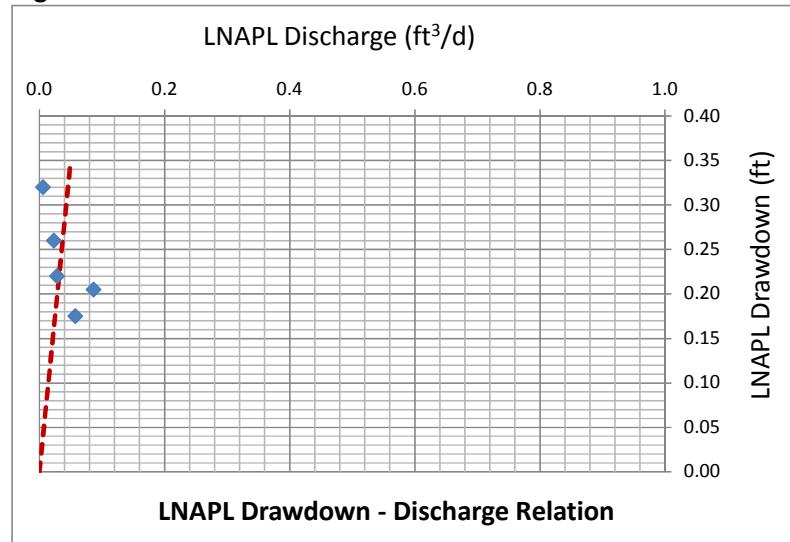
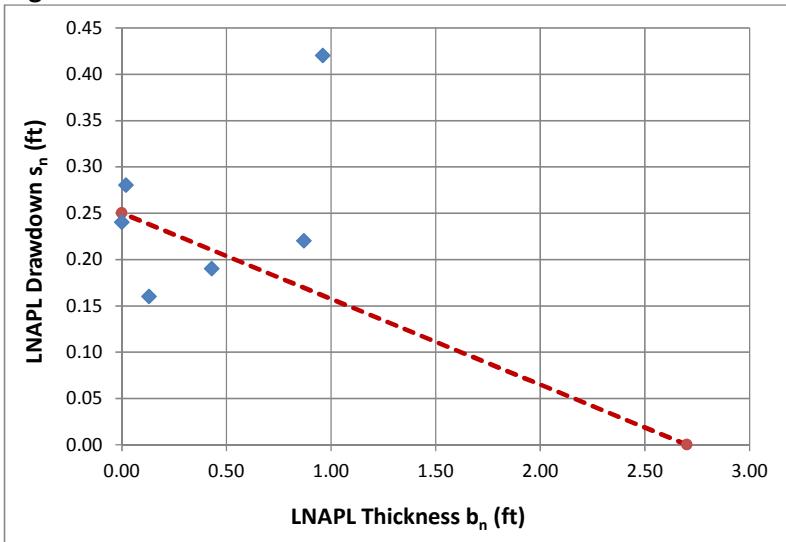
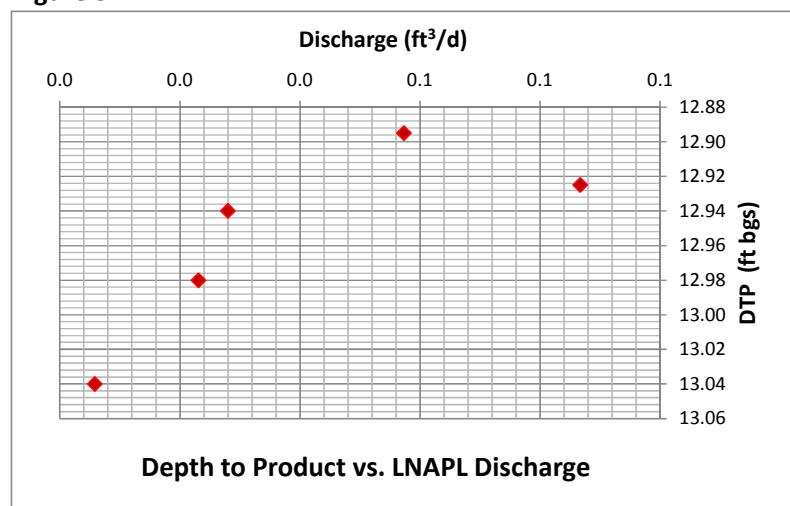
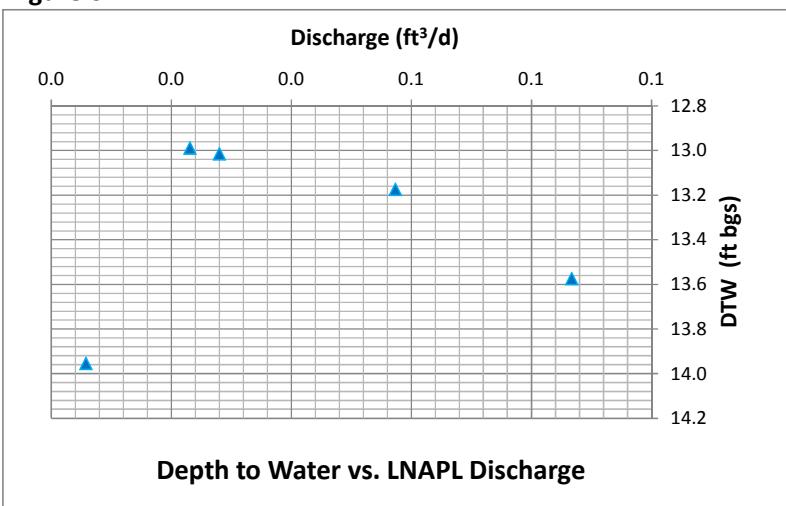
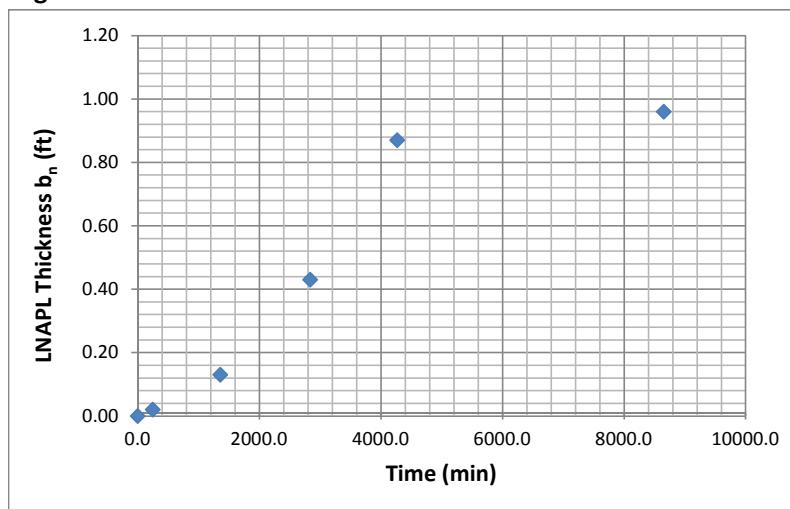
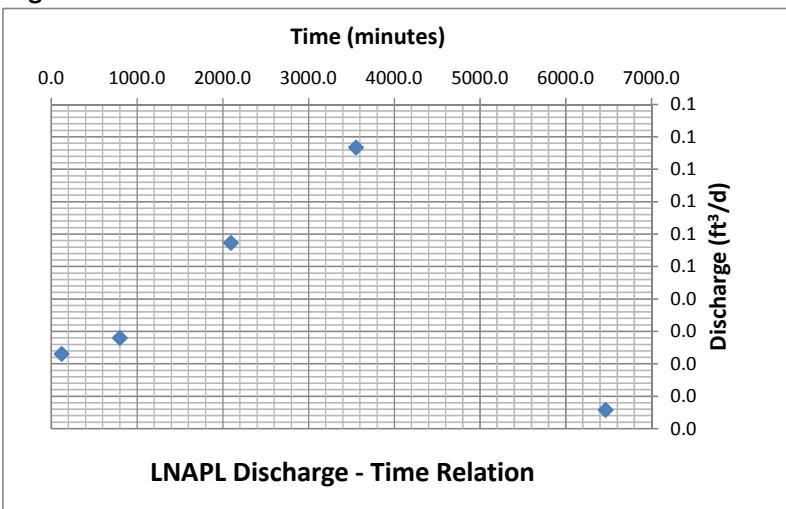
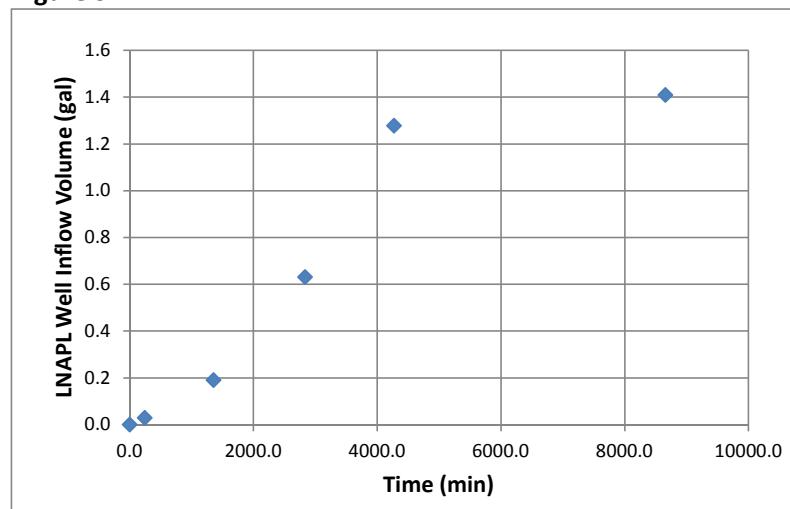
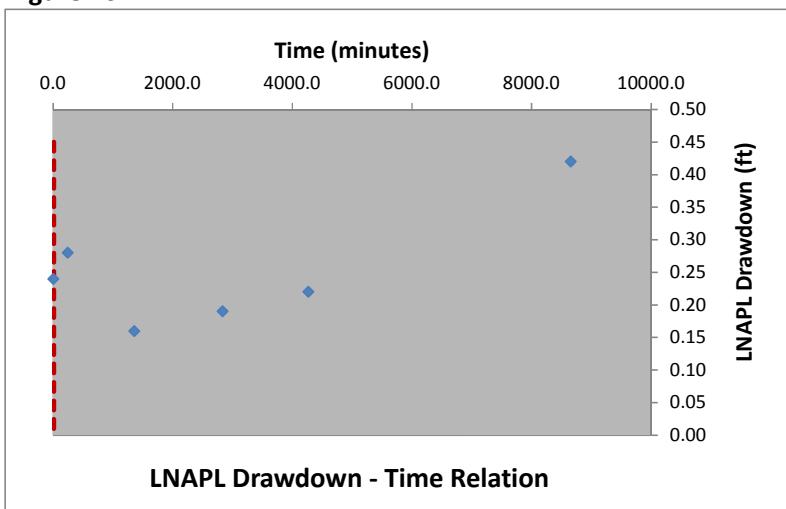
r_{e1}

Calculated Parameters

Eff NAPL Well Vo Fract NAPL Removed

1.23 1.86

Date and Time	Enter Data Here					Water Table Depth (ft)	LNAPL Drawdown s_n (ft)	LNAPL				
	Time (min)	DTP (ft btoc)	DTW (ft btoc)	DTP (ft bgs)	DTW (ft bgs)			Average Time (min)	Discharge Q_n (ft ³ /d)	s_n (ft)	b_n (ft)	r_e (ft)
4/21/15 10:32		12.72	14.4	12.72	14.4	12.87	0.24				1.68	
4/21/15 11:35	0.1	12.96	12.96	12.96	12.96	12.96	0.24				0.00	
4/21/15 15:40	245.0	13.00	13.02	13.00	13.02	13.00	0.28	122.6	0.023	0.26	0.02	0.250
4/22/15 10:10	1355.0	12.88	13.01	12.88	13.01	12.89	0.16	800.0	0.028	0.22	0.13	0.250
4/23/15 10:50	2835.0	12.91	13.34	12.91	13.34	12.95	0.19	2095.0	0.057	0.18	0.43	0.250
4/24/15 10:45	4270.0	12.94	13.81	12.94	13.81	13.02	0.22	3552.5	0.087	0.20	0.87	0.250
4/27/15 11:50	8655.0	13.14	14.10	13.14	14.10	13.23	0.42	6462.5	0.006	0.32	0.96	0.250
				#N/A	#N/A	#N/A	#N/A	0.0	#N/A	#N/A	#N/A	0.000
				#N/A	#N/A	#N/A	#N/A	0.0	#N/A	#N/A	#N/A	0.000

Figure 1**Figure 2****Figure 3****Figure 4****Figure 5****Figure 6****Figure 7****Figure 8****Figure 9****Figure 10**

Cooper and Jacob (1946)

Well Designation:	EW-1
Date:	21-Apr-15

$$V_n(t_i) = \sum_j^i \frac{4\pi T_n s_j}{\ln\left(\frac{2.25 T_n t_j}{r_e^2 S_n}\right)} \Delta t_j$$

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	200	<- Enter or change values here
Time Adjustment (min):	200	

Trial S_n: <- Enter d for default or enter S_n value

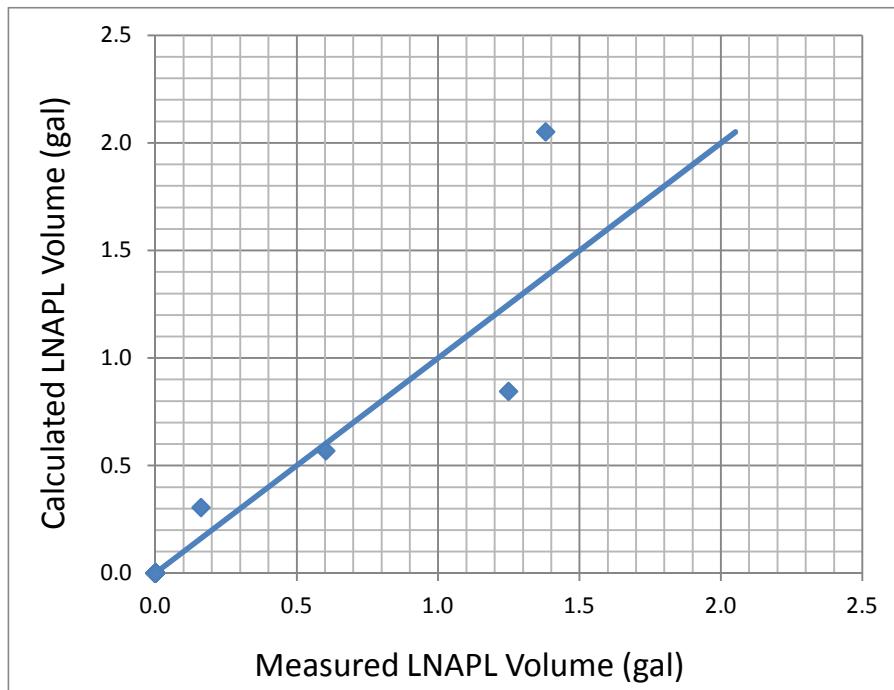
Root-Mean-Square Error: <- Minimize this using "Solver"

Trial T_n (ft²/d): <- Working S_n

Trial T_n (ft²/d): <- By changing T_n through "Solver"

Add constraint T_n > 0.00001

Model Result: $T_n (\text{ft}^2/\text{d}) = 0.10$



Cooper, Bredehoeft and Papadopoulos (1967)

Well Designation:	EW-1
Date:	21-Apr-15

Enter early time cut-off for least-squares model fit

Time _{cut} (min):	200	<- Enter or change values here
Initial Drawdown s _n (ft):	0.25	

Trial S_n: d <- Enter d for default

Root-Mean-Square Error: 1.185 <- Minimize this using "Solver"

Trial T_n (ft²/d): 0.090 <- By changing T_n through "Solver"

0.008 <- Working S_n

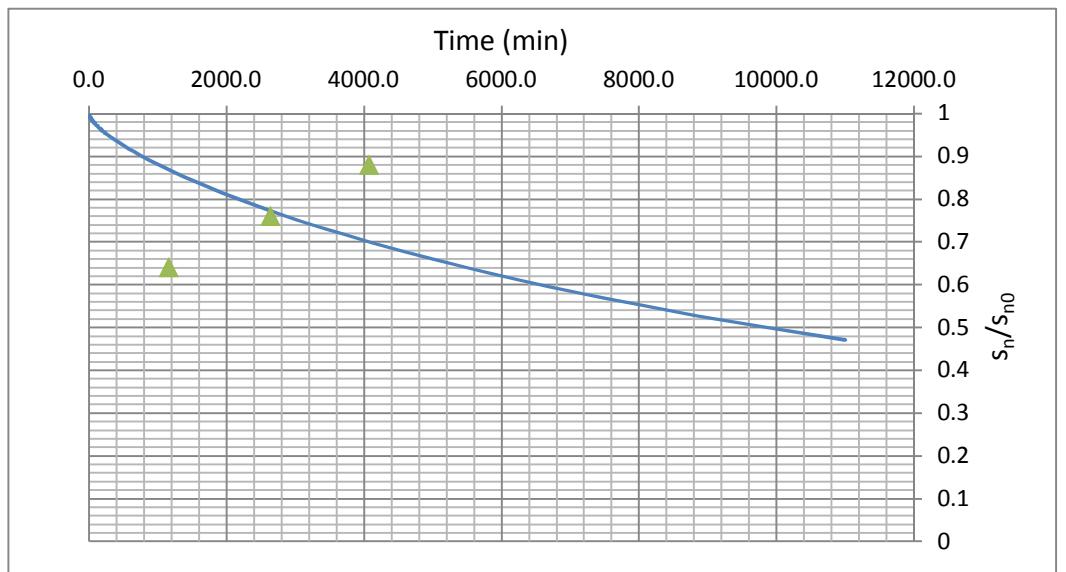
Add constraint Tn > 0.00001

Model Result:

T_n (ft²/d) =

0.09

T _{min}	0.2
T _{max}	11000



J-Ratio
-0.093

Thiem Equation:

$$T_n = \frac{Q_n \ln(R/r_w)}{2\pi(\text{AverageSn})}$$

Well Designation:	EW-1
Date:	21-Apr-15

Depth to base of confining bed (ft bgs) [from boring log]:	14
Constant LNAPL discharge to well (ft ³ /d):	0.040184

LNAPL drawdown, s_{nw} (ft):	0.25
Initial LNAPL thickness, b_{nr} (ft):	1.7
Radius of influence ratio (from Bouwer and Rice), R/r_w :	25.0

LNAPL Transmissivity, T_n (ft ² /d):	0.08
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